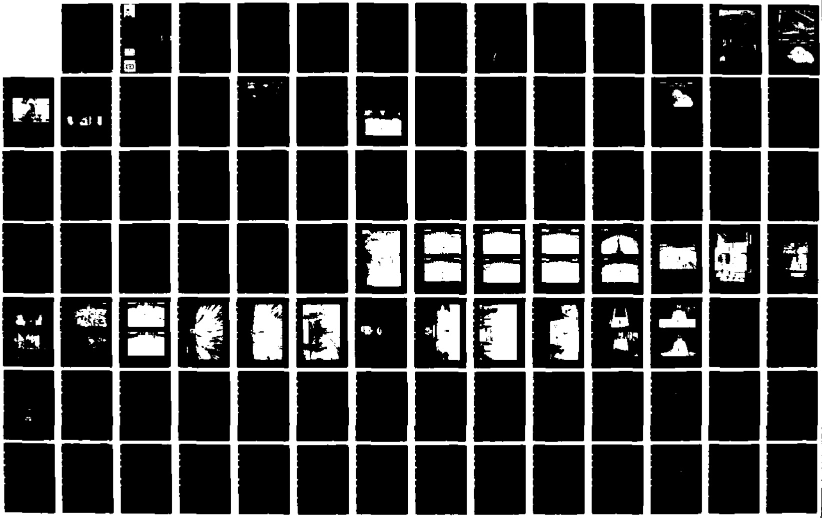
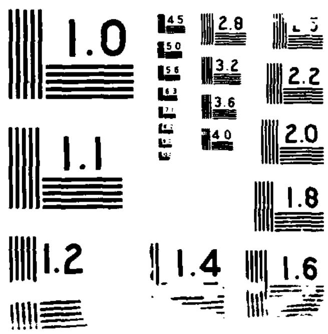
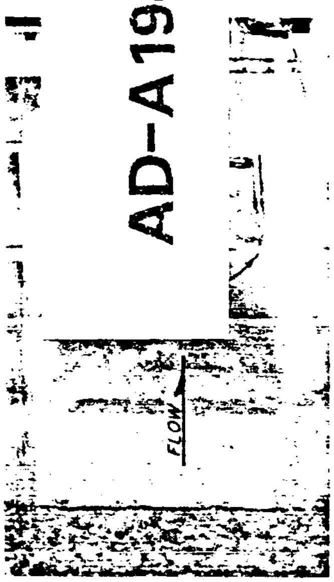
AD-A194 387 POND CREEK PUMPING STATION SOUTHWESTERN JEFFERSON
COUNTY KENTUCKY: HYDRAU (U) ARMY ENGINEER WATERWAYS
EXPERIMENT STATION VICKSBURG MS HYDRA.. B P FLETCHER
UNCLASSIFIED APR 88 WES/TR/HL-88-7 F/G 13/11 NL

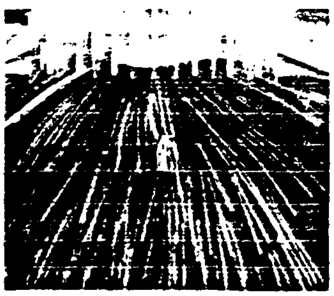



1.0
4.5
5.0
5.6
2.8
3.2
3.6
4.0
2.2
2.0
1.1
1.8
1.2
1.4
1.6

DTIC FILE COPY

AD-A194 387





US Army Corps of Engineers

TECHNICAL REPORT HL-88-7

POND CREEK PUMPING STATION SOUTHWESTERN JEFFERSON COUNTY, KENTUC

Hydraulic Model Investigation

by

Bobby P. Fletcher

Hydraulics Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39180-0631

US ARMY ENGINEER WATERWAYS EXPERIMENT STATION

April 1988

Final Report

Approved For Public Release; Distribution Unlimited

Prepared for US Army Engineer District, Louisville
Louisville, Kentucky 40201-0059

HYDRAULICS LABORATORY

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a REPORT SECURITY CLASSIFICATION Unclassified	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b DECLASSIFICATION/DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S) Technical Report HL-88-7	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION USAEWES Hydraulics Laboratory 6b OFFICE SYMBOL (If applicable) WESHS-S	7a NAME OF MONITORING ORGANIZATION
6c ADDRESS (City, State, and ZIP Code) PO Box 631 Vicksburg, MS 39180-0631	7b ADDRESS (City, State, and ZIP Code)
8a NAME OF FUNDING/SPONSORING ORGANIZATION USAED, Louisville 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State, and ZIP Code) PO Box 59 Louisville, KY 40201-0059	10 SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11 TITLE (Include Security Classification)
Pond Creek Pumping Station, Southwestern Jefferson County, Kentucky; Hydraulic Model Investigation

12 PERSONAL AUTHOR(S)
Fletcher, Bobby P.

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Final report	FROM ____ TO ____	April 1988	100

16 SUPPLEMENTARY NOTATION
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Baffle blocks; Gravity control; Stilling basin; Sump; Vortices

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

A 1:20-scale pumping station model of the sump and gravity control, approach, stilling basin, and exit channel was used to investigate and develop a practical design that would provide satisfactory hydraulic performance.

The pumping station and gravity control structures were combined by locating the gravity control below the sump. The pumping station consisted of four vertical pumps with a total capacity of 4,100 cfs. The gravity control section had a capacity for 17,000 cfs and consisted of an open-channel flow structure and tainter gate to maintain the pool. During operation of the pumps, surface vortices observed in the pump bays were eliminated by surface vortex suppressor beams. During operation of the gravity control structure, eddies and an unstable hydraulic jump observed in the stilling basin were eliminated by decreasing the rate of sidewall flare and strategically locating and increasing the height of the baffle blocks.

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION Unclassified
22a NAME OF RESPONSIBLE INDIVIDUAL	22b TELEPHONE (Include Area Code) / 22c OFFICE SYMBOL

PREFACE

The model investigation reported herein was authorized by the Office, Chief of Engineers (OCE), US Army, on 4 March 1976, at the request of the US Army Engineer District, Louisville (ORL).

The study was conducted periodically from May 1978 to May 1983 as funds were made available and as major design decisions were made. The work was conducted by personnel of the Hydraulics Laboratory of the US Army Engineer Waterways Experiment Station (WES) under the direction of Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory, and J. L. Grace, Jr., Chief of the Structures Division, and under the direct supervision of Mr. N. R. Oswalt, Chief of the Spillways and Channels Branch. The engineers in charge of the model were Messrs. E. D. Rothwell and B. P. Fletcher, Spillways and Channels Branch. The report was prepared by Mr. Fletcher and edited by Mrs. Marsha C. Gay, Information Technology Laboratory, WES. The following personnel are acknowledged for their special efforts on this project: Messrs. H. C. Greer III and S. W. Guy, Instrumentation Services Division, WES; and E. B. Williams and M. J. Tickell, Engineering and Construction Services Division, WES.

During the course of the investigation, Messrs. Jack Robertson and Sam Powell, OCE; Laszlo Varga, US Army Engineer Division, Ohio River; and Steve Michel, Jim Lapsley, Larry Curry, David Beatty, Byron McClellan, and Bill Brown, ORL, visited WES to discuss the program of model tests, observe the model in operation, and correlate test results with design studies.

COL Dwayne G. Lee, CE, is the Commander and Director of WES. Dr. Robert W. Whalin is the Technical Director.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acre-feet	1,233.489	cubic metres
cubic feet	0.028	cubic metres
degrees (angle)	0.01745329	radians
feet	0.305	metres
feet of water (39.2°F)	2,988.98	pascals
inches	25.4	millimetres
miles (US statute)	1.609	kilometres

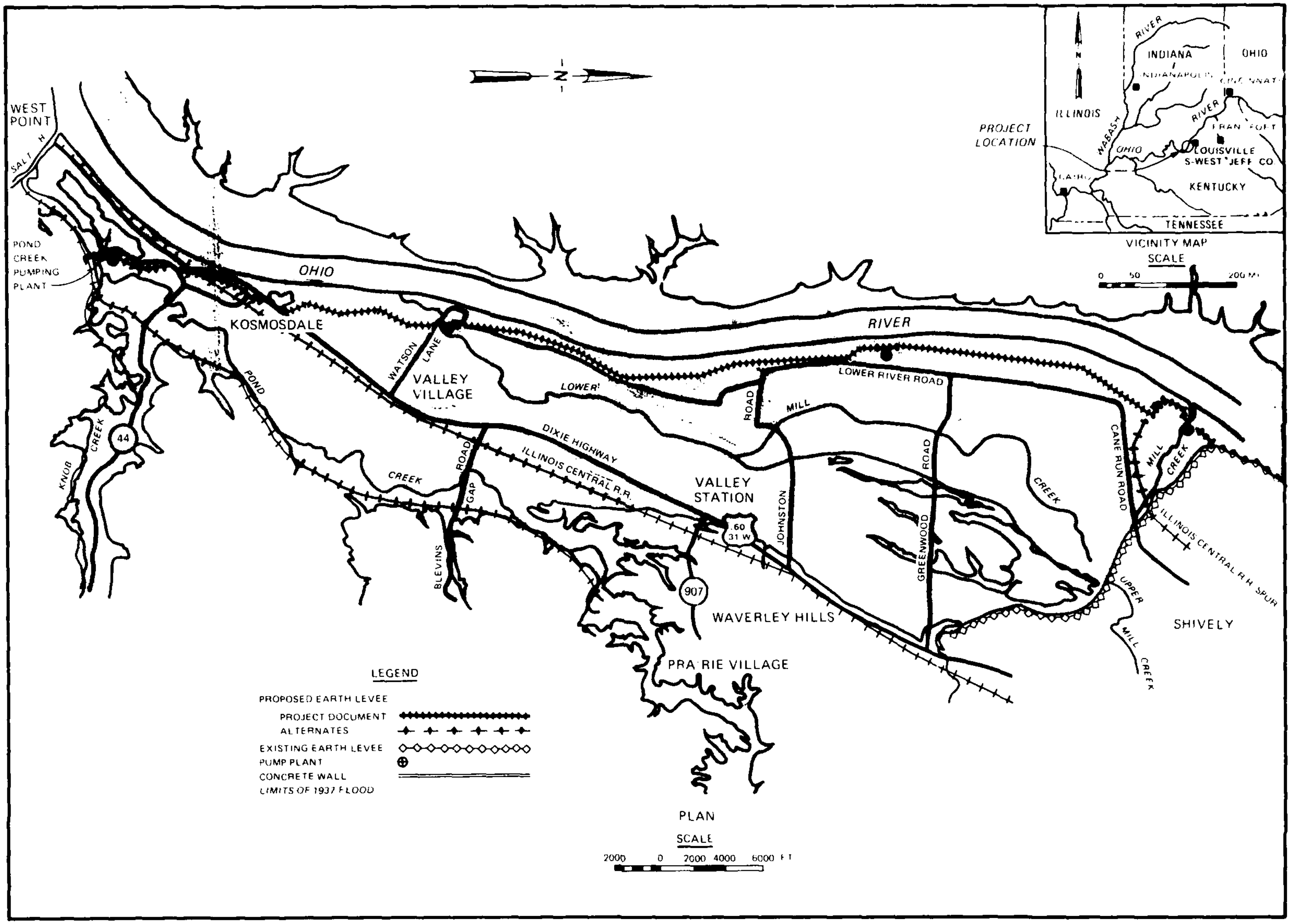


Figure 1. Location and vicinity map

POND CREEK PUMPING STATION

SOUTHWESTERN JEFFERSON COUNTY, KENTUCKY

Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototype

1. The proposed Pond Creek pumping station for the Southwestern Jefferson County local flood protection project is located on the east bank of the Ohio River about 50 miles* west of Frankfort, Kentucky (Figure 1).

2. The Pond Creek pumping station and gravity flow structure form the final link in the Southwestern Jefferson County local flood protection project. The pumping station consists of four bays, two on either side of the gravity flow structure (Plates 1-4). A trashrack is installed in each pump bay to prevent debris from entering the pump intakes.

3. The pumping station's four vertical pumps have an average total capacity of 4,100 cfs against hydrostatic heads from 8 to 27 ft. Storage of 13,200 acre-ft is provided between the pump starting elevation** of 421.0 ft and the 100-year design el of 432.0. The pumps discharge into flumes at the back of the combined structure which discharge into the stilling basin. Pump discharge always occurs under submerged stilling basin conditions.

4. The gravity flow structure consists of an open-channel flow structure (Plates 1-4) and tainter gate to maintain the pool, which discharges into a stilling basin.

5. The tainter gate is electronically controlled to permit regulation of the lake level and discharge into the stilling basin. The stilling basin width (54 ft) is based on a design velocity of 12.0 fps over the end sill with tailwater at el 412.5. The length of the basin (100 ft) is about 3.5 times D_2 (theoretical sequent depth required for a hydraulic jump).

---

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

** All elevations (el) and stages cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

6. The exit channel is lined with riprap and has a 54-ft bottom width and 1V on 3H side slopes.

Purpose and Scope of Model Study

7. The model study was conducted to evaluate the hydraulic characteristics and develop modifications required for a satisfactory design of the approach channel, sump, gravity outlet, and exit channel. Tests were also conducted to determine the size and extent of rock protection required downstream from the gravity outlet. The model provided information necessary for development of a design that will provide satisfactory hydraulic performance for all anticipated flow conditions.

PART II: THE MODELS

Description

8. Initially, the sump and gravity flow outlet were designed to be separate, and separate models were used to investigate the sump and gravity flow outlet.

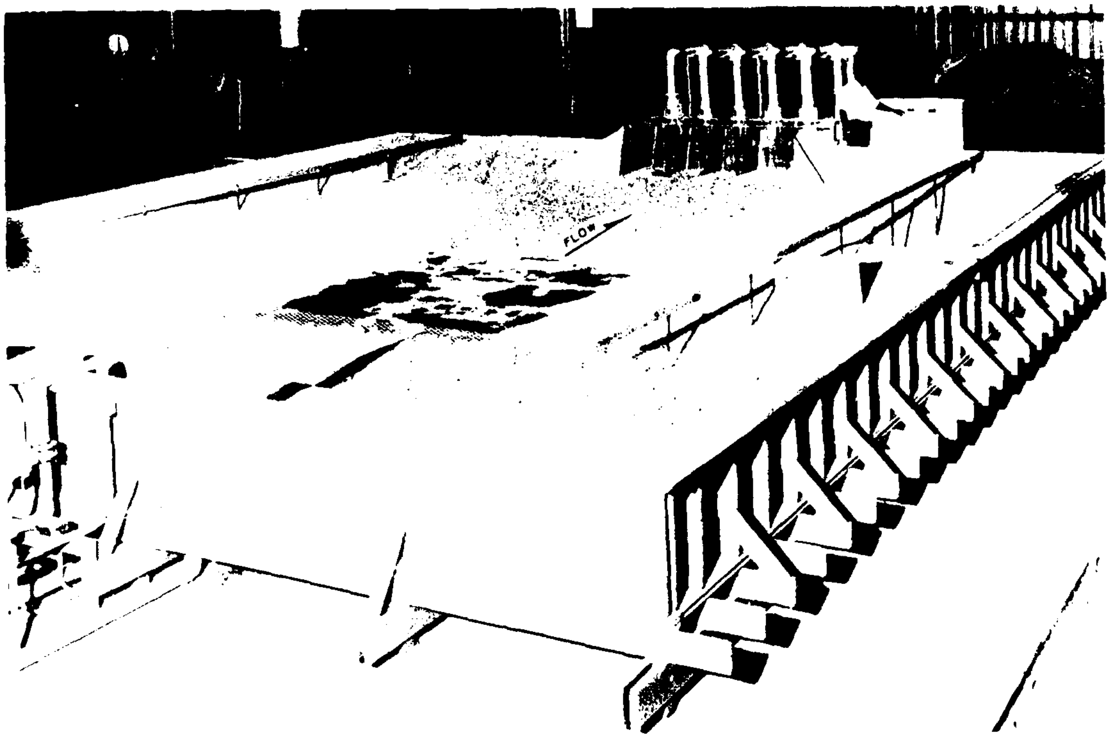
9. The model to investigate the sump (Figure 2a) was constructed to a linear scale of 1:20 and reproduced a 700-ft length by 700-ft width of the approach channel, sump, and five pump intakes. Flow through each pump intake was provided by individual suction pumps that permitted simulation of various flow rates through one or more intakes.

10. The model to investigate the gravity flow section was also constructed to a linear scale of 1:20 and reproduced a 600-ft-long and 500-ft-wide area of approach (Figure 2b), the gravity flow section, discharge conduit, stilling basin, and a 400-ft-long and 500-ft-wide exit channel (Figure 2c).

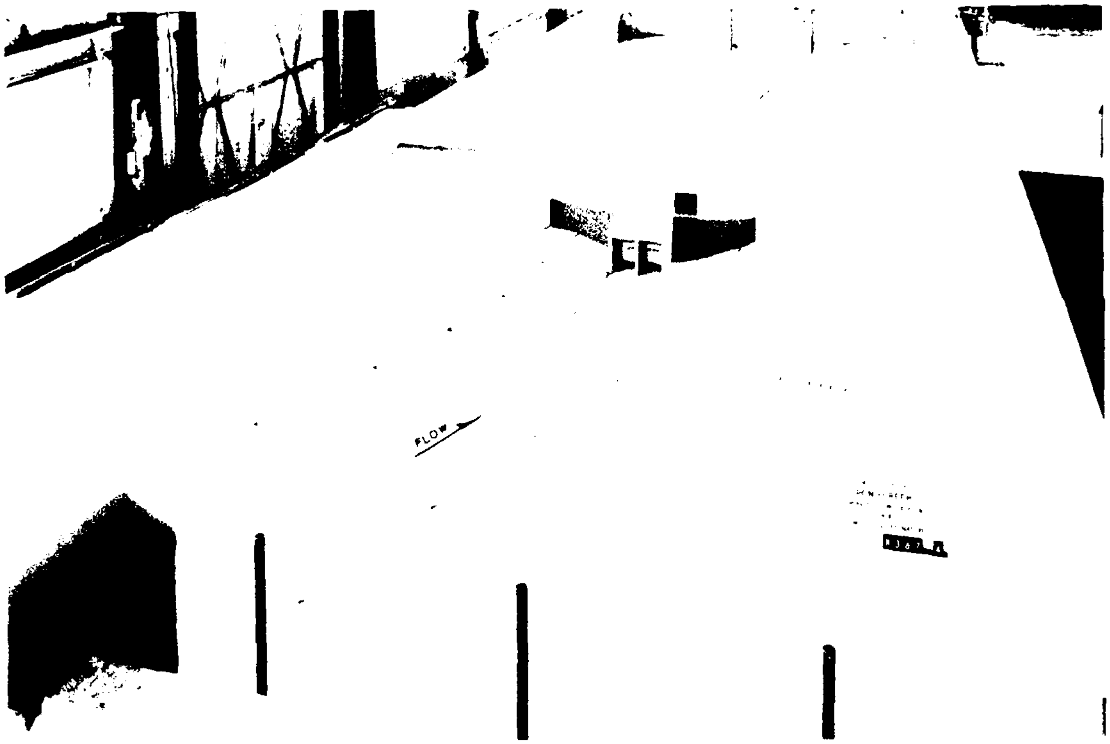
11. Following tests of a separate gravity flow outlet and sump, the sump model was modified to enable investigation of a 1:20-scale, combined gravity flow outlet and sump (Figures 2d and 2e).

12. The pump intakes and a portion of the model were transparent to permit observation of subsurface and surface vortices, current patterns, and turbulence. A stage C, D, or E vortex (Figure 3) was considered unacceptable. A stage E vortex is shown in Figure 4. Pressure fluctuations at each pump intake were measured by 8.0-in.-diam (prototype) electronic pressure cells (Figures 4 and 5) flush with the floor of the sump directly below the center line of the pump column. Pressure fluctuations in excess of 3.0 ft (prototype) were considered unacceptable. Swirl in the pump intakes was measured by vortimeters (free-wheeling propellers with zero pitch blades) located inside each pump intake at the approximate position of the prototype pump propeller (Figure 4). Propeller rotation in excess of 2 rpm (prototype) was considered unacceptable.

13. Water used in the models was recycled and discharges were measured with venturi and turbine flowmeters. Water-surface elevations were measured with staff and point gages. Velocities were measured with pitot tubes and electromagnetic velocity probes. Current patterns were determined by

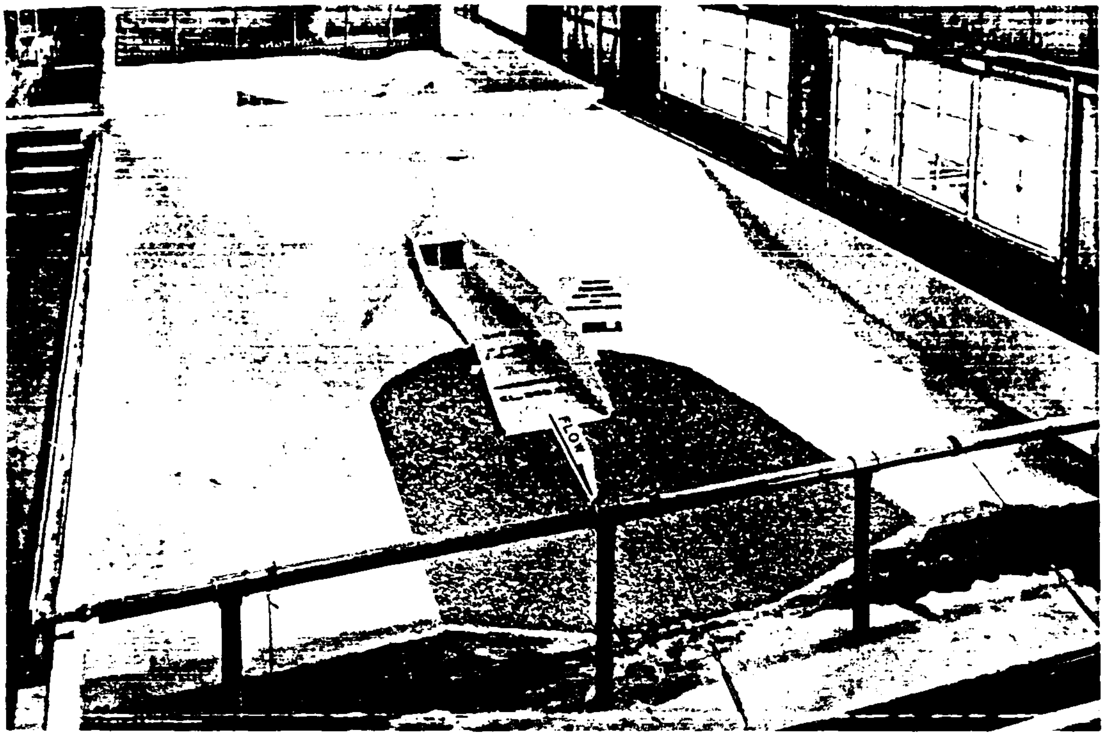


a. Sump

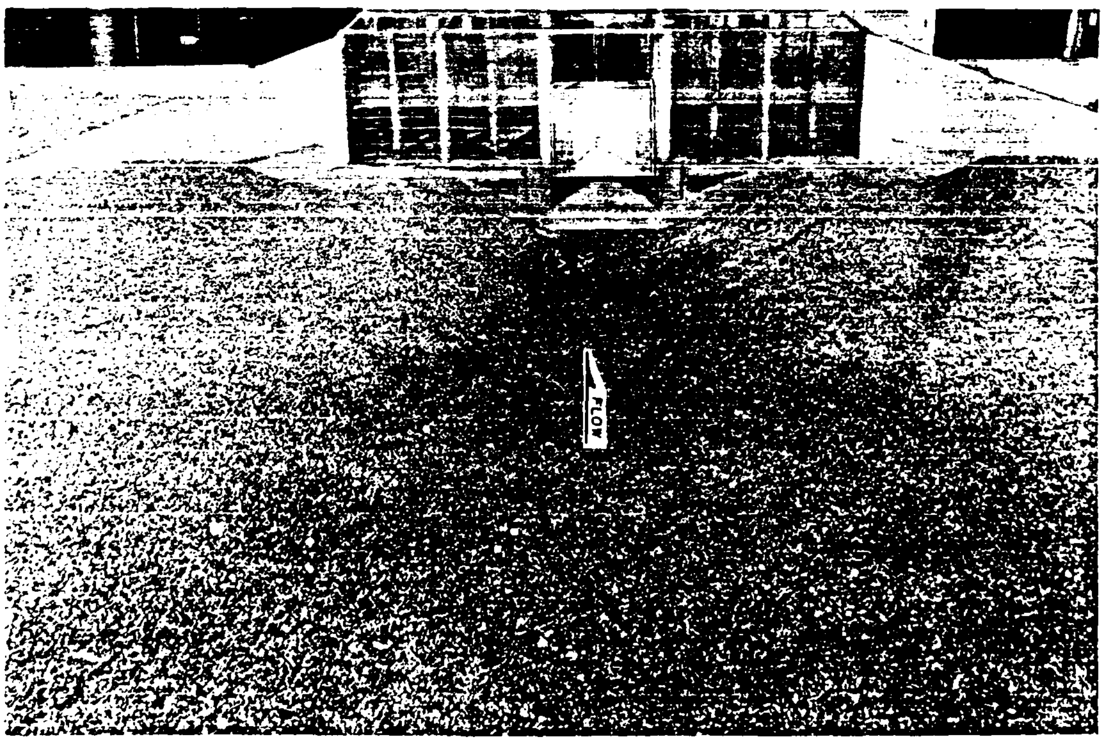


b. Gravity flow intake

Figure 2. The 1:20-scale models (Sheet 1 of 3)

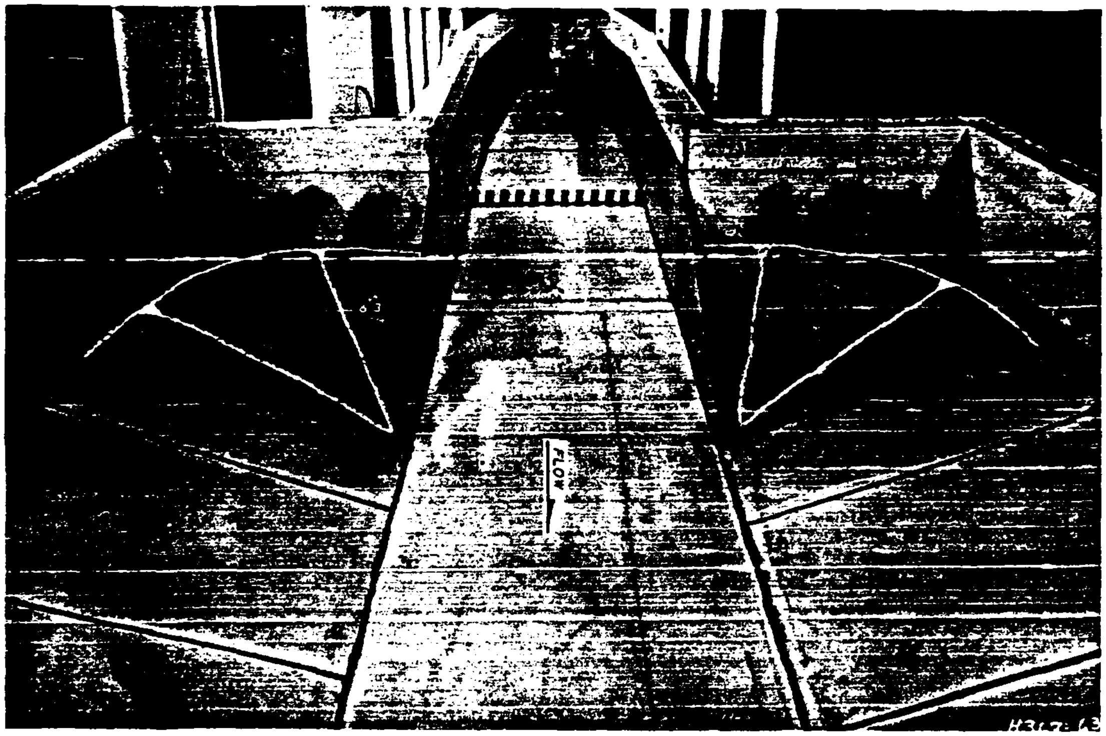


c. Gravity flow outlet



d. Combined sump and gravity flow intake

Figure 2. (Sheet 2 of 3)



e. Combined sump and gravity flow outlet

Figure 2. (Sheet 3 of 3)

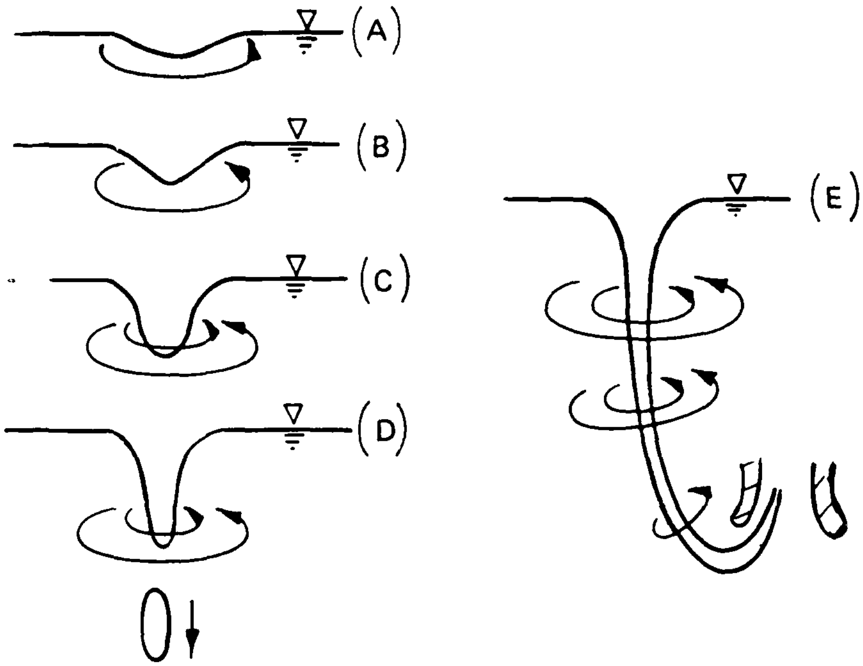


Figure 3. Stages in development of
air-entraining vortex

Figure 4. Vortimeter and pressure cell

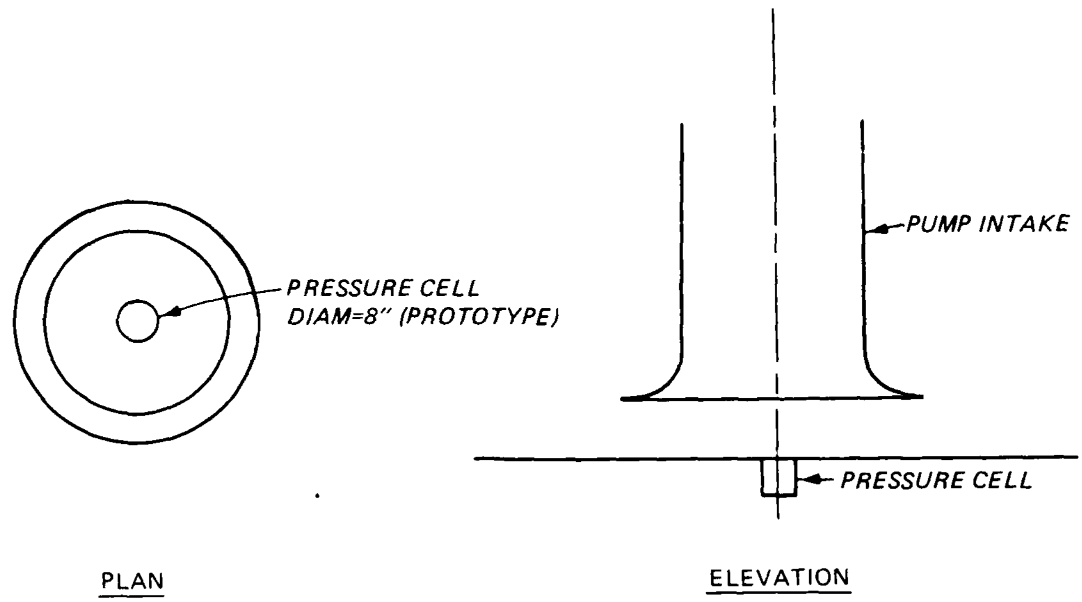


Figure 5. Pressure cell location

observation of dye injected into the water and confetti sprinkled on the water surface.

Interpretation of Model Results

14. The accepted equations of hydraulic similitude, based upon Froude criteria, were used to express the following mathematical relations between the dimensions and hydraulic quantities of the models and prototypes:

Dimension	Ratio	Scale Relation Model:Prototype
Length	$L_r = L_r$	1:20
Area	$A_r = L_r^2$	1:400
Velocity	$V_r = L_r^{1/2}$	1:4.47
Discharge	$Q_r = L_r^{5/2}$	1:1,789
Time	$T_r = L_r^{1/2}$	1:4.47
Pressure	$P_r = L_r$	1:20
Weight	$W_r = L_r^3$	1:8,000

PART III: TEST RESULTS

15. Initially, the two structures were to be located several hundred feet apart to ensure symmetrical inflow to the pumping station sump. Initial model tests were conducted with separate 1:20-scale models of the gravity flow outlet and the pumping station sump (Figures 2a, b, and c).

16. Model tests showed that the sump for the pumping plant functioned well; however, the gravity structure required an expensive wing wall designed to prevent vortex development (Photo 1) during major floods. Structural studies in the prototype showed that the wing walls would be expensive and difficult to build.

Scheme A

17. Based on high projected costs for the separate structures and discussions among personnel of the US Army Engineer District, Louisville, US Army Engineer Waterways Experiment Station (WES), and US Army Engineer Division, Ohio River, it was decided to investigate the feasibility of an over/under pumping and gravity flow scheme. The gravity control was located below the sump.

Sump

18. The Scheme A type 1 sump (Figure 6) appeared to be satisfactory for sump water elevations equal to or higher than 426.0 ft. However, unsymmetrical flow distribution was later observed inside the pump bays. The submergence available with sump water surface at el 426.0 appeared to be sufficient to negate potential undesirable flow characteristics that are normally generated by uneven lateral flow distribution to the pump intakes. At the minimum anticipated sump water-surface elevation (421.0 ft), adverse flow distribution and severe surface vortices were observed near the pumps as shown in Plates 5-7. Flow performance observed in the type 1 design sump with various water-surface elevations and combinations of pumps operating is indicated by pressure fluctuations, swirl, and vortex development presented in Table 1. The performance indicators presented in Table 1 show that with sump water surface at el 421.0, air-entraining vortices are the primary undesirable hydraulic characteristic.

19. Modifications in the approach to reduce the unsymmetrical current

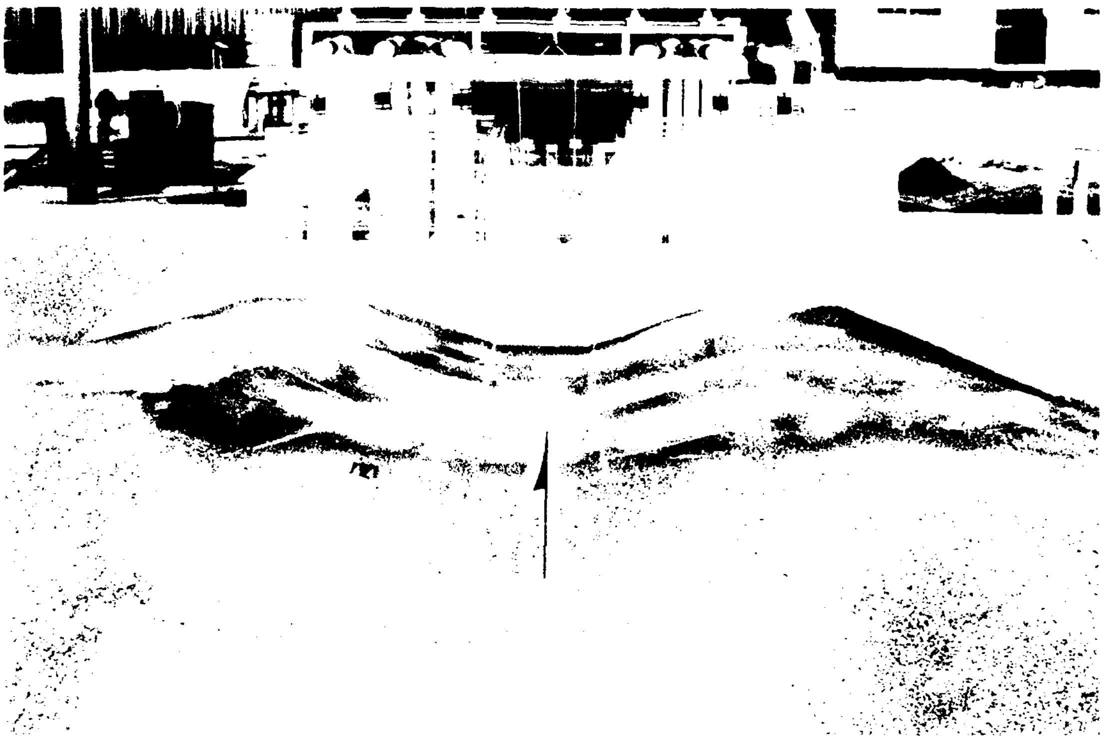


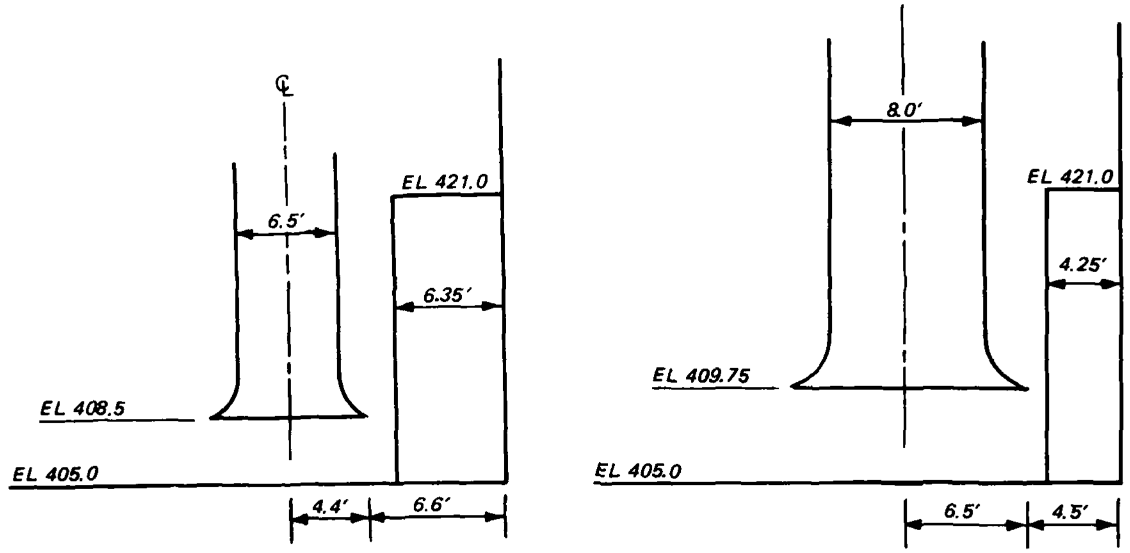
Figure 6. Combined pumping station and gravity control, Scheme A

distribution and associated vortices in the pump bays were not considered practical. Efforts to develop a satisfactory design were directed toward modifying the interior of the pump bays.

20. Initially a false backwall, as shown in Figure 7, was installed within 0.25 ft from the edge of the suction bell (Scheme A type 2 design sump). Tests indicated that the false backwall with a top at el 421.0 was effective only with sump water surface at el 421.0.

21. Additional tests conducted with the top of the false backwall located at various elevations indicated that it was most effective with the top located at el 426.0 or higher (Scheme A type 3 design sump), as shown in Figure 8. Hydraulic characteristics in the sump would be similar with the edge of the suction bell located either 0.25 ft from the false backwall or 0.75 ft from the actual backwall. Although the Scheme A type 3 design sump provided a significant improvement in hydraulic performance, occasional surface depressions (stage C vortices) developed near the pump column.

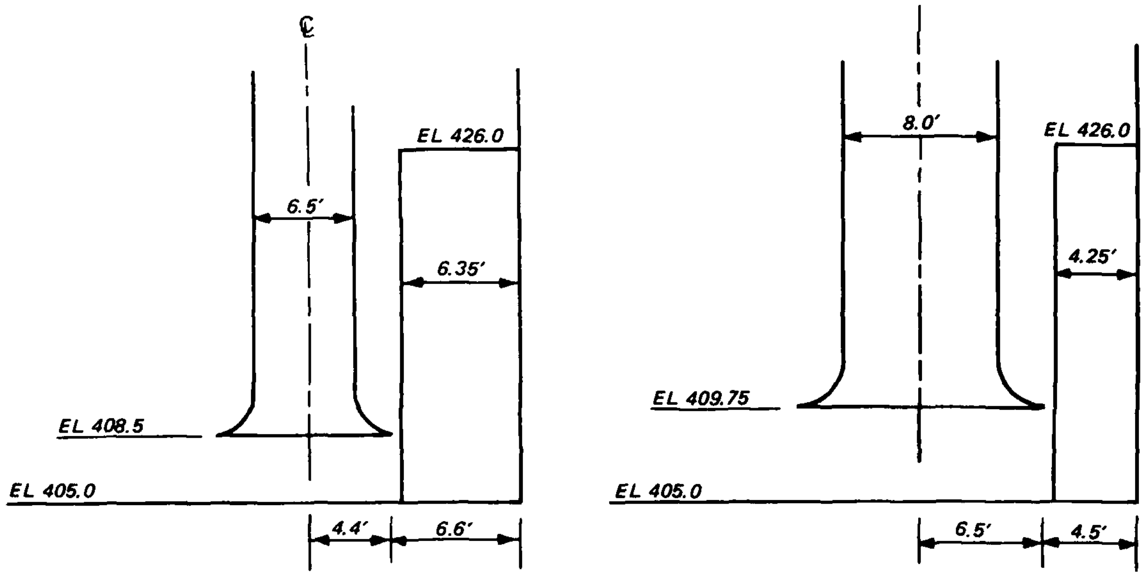
22. Various sizes of vortex suppressors designed to attenuate or eliminate vortex development by generating small-scale surface turbulence were investigated at various positions upstream from the pump columns. Test



a. Pumps 1 and 6

b. Pumps 2, 3, 4, and 5

Figure 7. Scheme A type 2 sump



a. Pumps 1 and 6

b. Pumps 2, 3, 4, and 5

Figure 8. Scheme A type 3 sump

results indicated that 3-ft-high vortex suppressors were most effective when positioned as shown in Plate 8 (Scheme A type 4 design sump). The Scheme A type 4 design sump provided satisfactory flow conditions in the sump for all anticipated water-surface elevations and combinations of pumps operating. Performance indicators obtained with the type 4 sump design (Plate 8) are tabulated in Table 2.

23. The Louisville District determined that it would be structurally desirable to locate a pier in the center of each pump bay (type 5 sump), shown in Figure 9 and Plate 9. Tests indicated no significant change in hydraulic performance due to the piers. The magnitude and direction of currents approaching the pump intakes in the approach and along the approach training wall for minimum anticipated sump at el 421.0 and maximum pumping discharge of 4,100 cfs are shown in Plates 9 and 10, respectively. Riprap (thickness = 12 in. and average size of stone (d_{50}) = 6 in.) in the approach (Figure 9) was stable for all anticipated pumped flows and headwater elevations. Various flow conditions taken with a 100-sec (prototype) exposure time are shown in Photo 2.

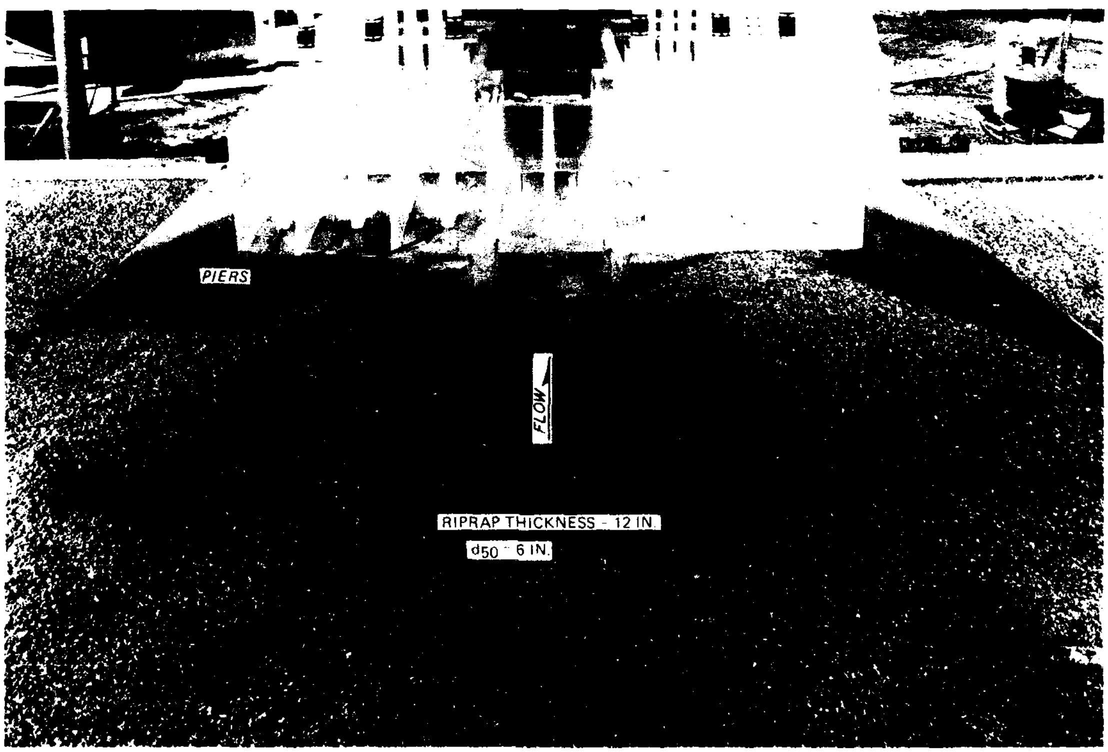


Figure 9. Scheme A type 5 sump, type 1 riprap

Gravity control

24. The approach to the Scheme A type 1 gravity flow outlet is shown in Figure 6. A self-regulating tainter gate (autogate) (Plate 11) located in the upper gravity bay was designed to maintain the recreation pool within 3 ft of el 421.0. In the prototype, the autogate automatically adjusts its opening relative to the head on the gate. In the model the autogate was schematically simulated. The autogate is designed to pass flows as high as 2,000 cfs. When the pond level exceeds el 424.0, the roller gates (Plate 11) will be opened to provide flow through the twin 15- by 15-ft conduits in the lower gravity bay. A divider wall was installed in the center of the entrance to the gravity control structure (Scheme A type 2 gravity control) to provide additional support for the bulkheads, and a quadrant wall (Scheme A type 3 gravity control) was added to provide streamlining (Plates 11 and 12).

25. A discharge rating curve for free-flow conditions and with the roller gates open to el 421.0 is shown in Figure 10. The rating curve indicates that with the roller gates open to el 421.0, the structure will not pass the design discharge of 15,000 cfs with pool at el 432.0. Flow with the roller gates open to el 421.0 generated severe turbulence (Plate 13) that significantly reduced the hydraulic capacity of the structure. A representative of the Louisville District stated that the structure could be operated with the roller gates opened to el 405.0.

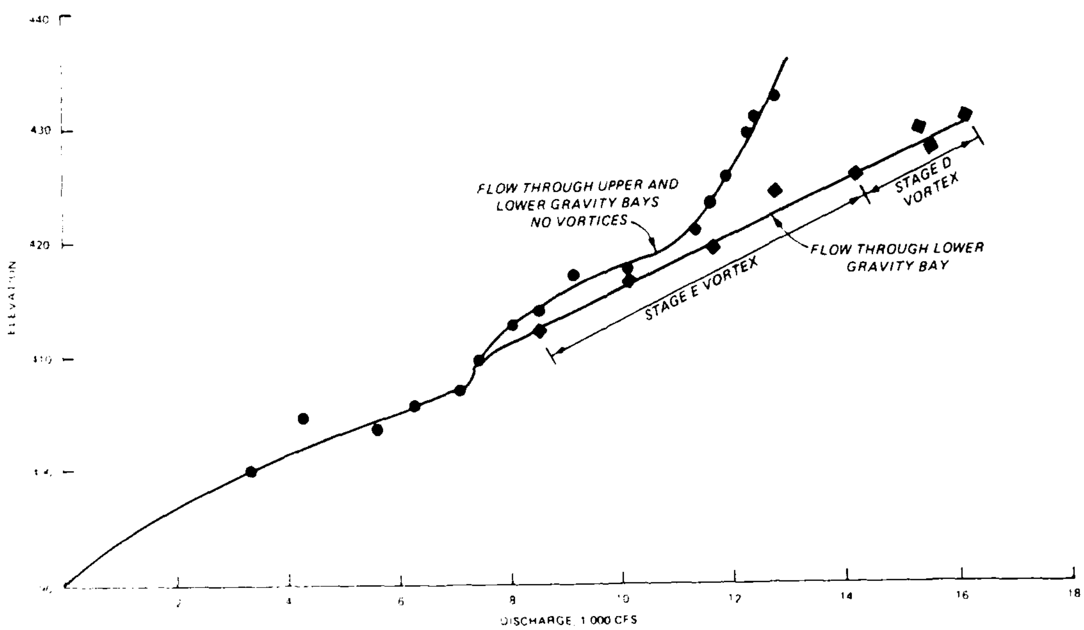


Figure 10. Rating curve, Scheme A type 3 gravity flow

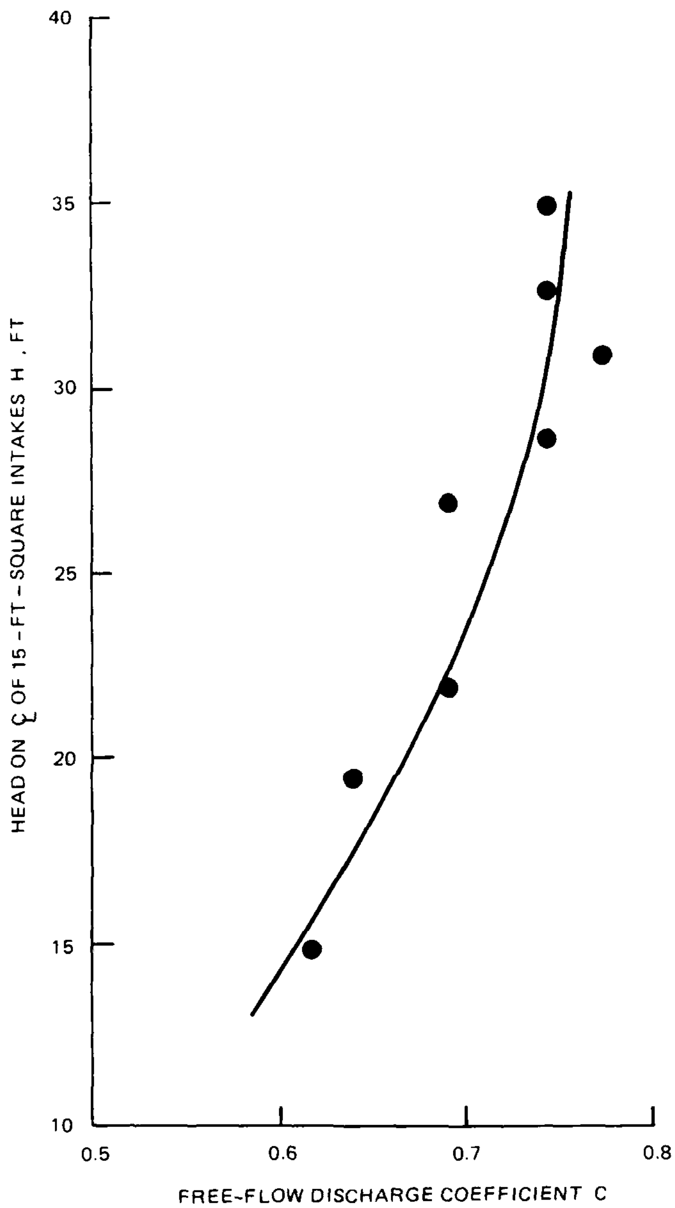
26. The roller gates were opened to el 405.0 and flow conditions (discharge Q of 15,000 cfs) were observed as shown in Plate 11. The capacity of the structure was significantly increased as indicated by the rating curve in Figure 10. The increased capacity was attributed to reduction of turbulence inside the structure (compare Plates 11 and 13). An occasional air-entraining vortex occurred at the inlet as shown in Plate 12 and Figure 10. Figure 10 shows a range of discharges where stage D and E vortices occurred. The occasional vortices did not cause any significant problems, and flow characteristics throughout the Scheme A type 3 gravity control structure appeared satisfactory for the range of anticipated flows.

27. A plot of heads on the center line of the culverts versus discharge coefficients for the structure with the roller gates open to el 405.0 is shown in Figure 11. Basic free-flow data obtained with the model are tabulated in Table 3. Various approach flow conditions taken with a 50-sec (prototype) exposure time are shown in Photo 3. The magnitude of currents approaching the gravity flow intake along the approach training wall for the maximum gravity flow of 15,000 cfs and pool at el 428.0 is shown in Plate 10.

28. Tests conducted to investigate the feasibility of removing the portion of the divider wall located between the gravity flow conduits (the shaded area in Plate 12) indicated that the downstream portion of the wall is needed to direct the flow and minimize turbulence. Flow with the divider wall installed is shown in Photo 4. Submerged flow with a discharge of 15,000 cfs through the lower gravity bay generated turbulence and waves 1 ft high near the autogate (Photo 5). Although the turbulence and waves were considered nondamaging, the Louisville District requested that the autogate be moved upstream of the roller gates to provide better access for maintenance and operation. The model results indicated that moving the autogate upstream of the roller gate would not adversely affect the hydraulic performance of the structure. A discharge of 2,000 cfs passing through the upper gravity bay is shown in Photo 6.

Riprap

29. The Scheme A type 1 riprap (d_{50} = 6 in.) in the approach (Figure 9) failed from the intake to a point 20 ft upstream as shown in Plate 14 when subjected to a gravity flow of 15,000 cfs. Turbulence associated with the bottom roller and vortices generated by the abutments, shown in Plate 12, caused the riprap to fail. The riprap thickness was increased to 50 in. with



NOTE: $Q = C A \sqrt{2gH}$

Q = DISCHARGE, CFS

A = AREA OF CULVERTS, FT^2

g = ACCELERATION DUE TO GRAVITY, FT/SEC^2

H = HEAD ON ℄ OF 15-FT-SQUARE INTAKES (EL 397.5), FT

Figure 11. Scheme A type 3 gravity control

a d_{50} of 25 in. for a distance of 20 ft upstream from the structure (Scheme A type 2 riprap). Rock failure occurred from the intake to a point about 5 ft upstream. Therefore, it was recommended that the full width of approach to the gravity flow section be paved with concrete for 20 ft upstream of the entrance. The 12-in. thickness was adequate upstream from this location.

Scheme B

30. Value engineering studies by the Louisville District indicated that it would be cost effective to reduce the number of pumps from six to four. The 1:20-scale model was revised to simulate Scheme B, which contained four 1,025-cfs pumps with a gravity flow section located in the center (Plate 15). The gravity flow outlet was not changed.

31. The magnitudes and directions of currents measured 1 ft above the bottom of the approach and the sump with various pumps operating are shown in Plates 16-19. Only minor flow contractions were observed at the pier noses. Rotational flow tendencies (swirl) and stages of vortex development are presented in Table 4. Submerged or surface air-entraining vortices were not observed. Only occasional surface swirls or depressions (stage A vortex) were observed with the minimum water-surface elevation.

32. Performance of the Scheme B sump was considered satisfactory for the range of anticipated water-surface elevations with any single pump or combination of pumps operating.

Scheme C (Adopted Design)

33. Engineers from the Louisville District decided, based on additional value engineering studies, that a single tainter gate having the same width as the gravity bay (34 ft) with the invert of the gravity bay at el 390.0 would increase the capacity of the gravity flow and reduce the structural costs. Also, the length of the pump bays was reduced to 54 ft. The model was revised to simulate the Scheme C design, which contained four 1,025-cfs pumps with a tainter-gate-controlled gravity flow section located in the center bay (Figure 12 and Plate 20).

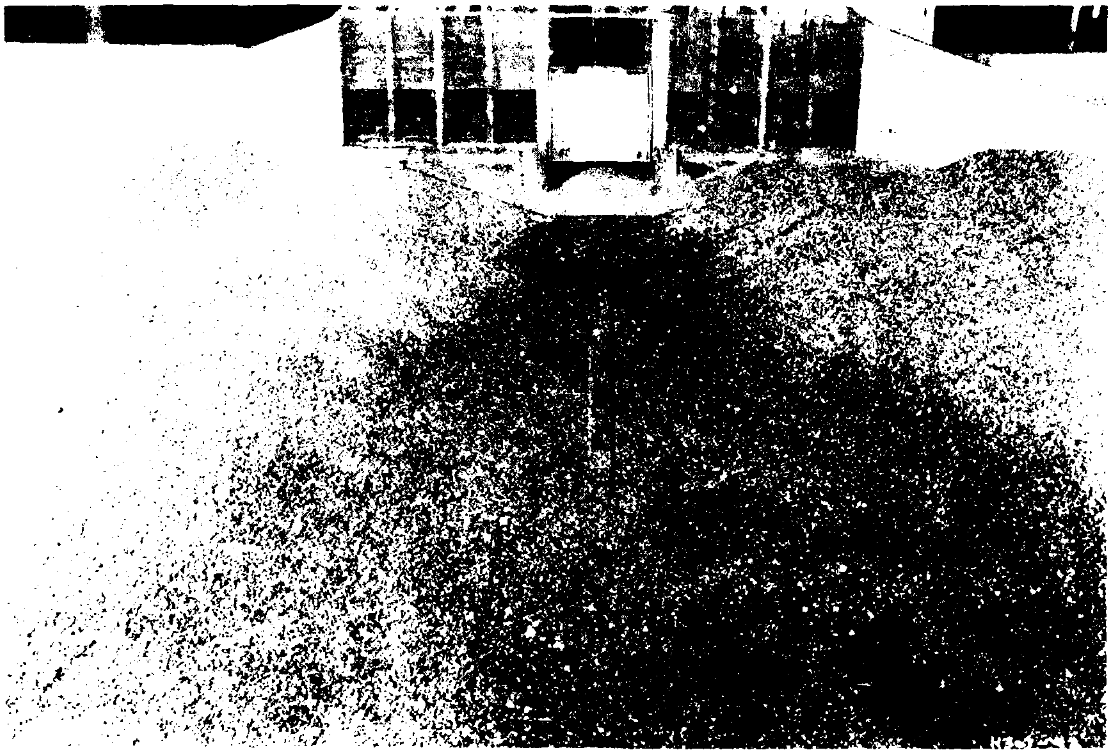


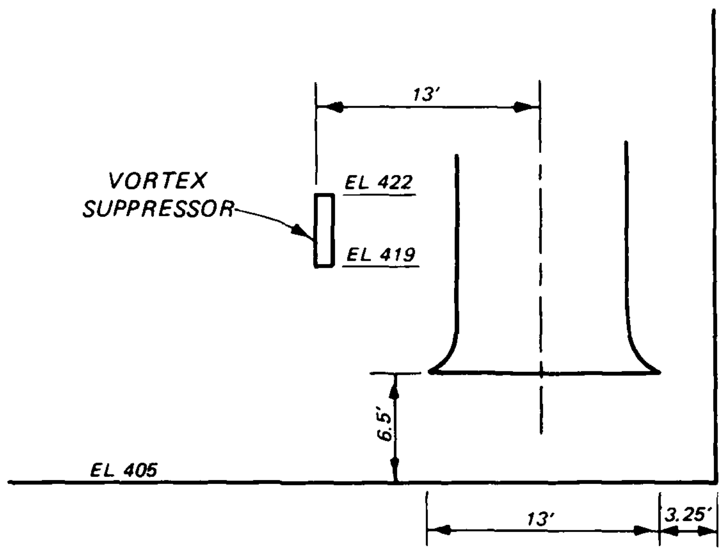
Figure 12. View from upstream, Scheme C

Sump

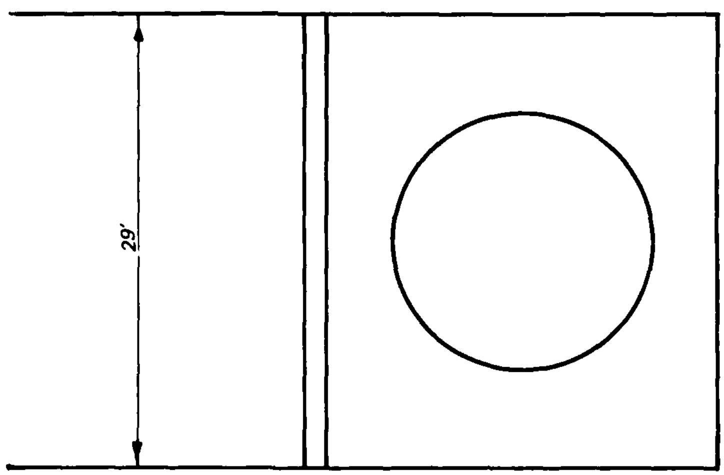
34. Based on test results obtained from a general research study of sump performance conducted at WES,* a pump and vortex suppressor beam were located in each bay of the sump as shown in Figure 13. Results from the general research indicated that the pump location shown in Figure 13 was the least susceptible to submerged vortices, and the vortex suppressor beams would eliminate surface vortices.

35. The magnitudes and directions of currents measured 1 ft above the bottom with various pumps operating are shown in Plates 21-25. Various approach flows are shown in Photo 7. For some flow conditions, flow contractions observed at the abutments and pier noses induced unevenly distributed currents as flow entered the bays. As flow passed through the bays and approached the pump intakes, currents became more evenly distributed. Pressure fluctuations beneath the pumps, rotational flow tendencies (swirl), and stages

* Glenn R. Triplett, Bobby P. Fletcher, John L. Grace, John J. Robertson. 1988 (Feb). "Pumping Station Inflow-Discharge Hydraulics, Generalized Pump Sump Research Study," Technical Report HL-88-2, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.



a. Elevation



b. Plan

Figure 13. Pump location, Scheme C type 1 suction bell

of vortex development are presented in Table 5. Virtually no surface vortices (none worse than stage A) occurred when vortex suppressor beams were in place. Removal of the vortex suppressors resulted in stage D and E vortices in all pumping bays. Pressure fluctuations below the center line of the pump intake and swirl inside the pump column were insignificant in all instances. No submerged vortices occurred for any condition.

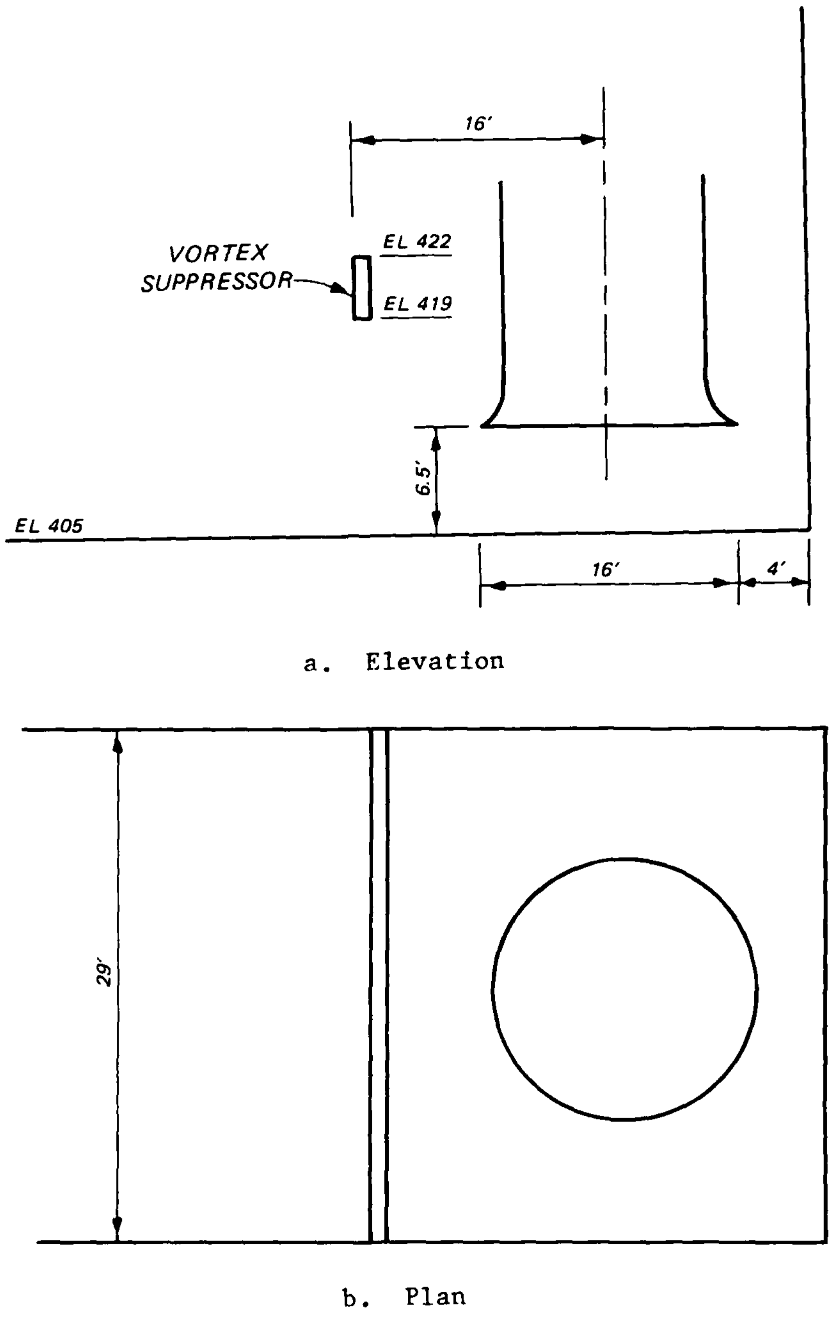
36. The suction bell diameter was increased from 13 ft (type 1) to 16 ft (type 2). The Scheme C sump with the 16-ft-diam type 2 suction bell is shown in Figure 14. Tests were conducted for all anticipated water-surface elevations in the sump and for all possible combinations of single and multiple pump operation. Test results indicated that for all conditions, hydraulic performance in the approach and sump was satisfactory and almost identical to that documented with the 13-ft-diam suction bell installed.

Gravity control

37. The gravity flow control structure (Plate 20) was evaluated for discharges up to the design discharge of 17,000 cfs. Approach flows were satisfactory and are shown in Photos 8 and 9. Approach velocities measured near the bottom are provided in Plate 20.

38. Controlled flow. Observations indicated that an air-entraining vortex developed upstream and on each side of the tainter gate (Plate 26 and Photo 10) for all controlled flows greater than 1,300 cfs. Development of the vortices appeared to be initiated by flow contraction at each abutment. The vortex at the right abutment (looking downstream) was usually stronger than the vortex at the left abutment. This was probably due to the lower elevation of the topography in the approach on the right side which permitted more flow to approach the structure laterally from the right and caused more flow contraction at the right abutment. Various heights (2, 3, 5, and 7 ft) of vortex suppressor beams were installed at various locations upstream from the tainter gate. The most effective beam (type 2 gravity flow) was 5 ft high and was located 4 ft downstream from the nose of the abutment (Figure 15). The beam eliminated all air-entraining vortices for all anticipated flow conditions. Some flow conditions allowed an eddy to form on each side immediately upstream from the vortex suppressor beam (Figure 15). The eddies were eliminated by providing a transition (fillet) from the pier nose to the beam (type 3 gravity flow) as shown in Figure 16.

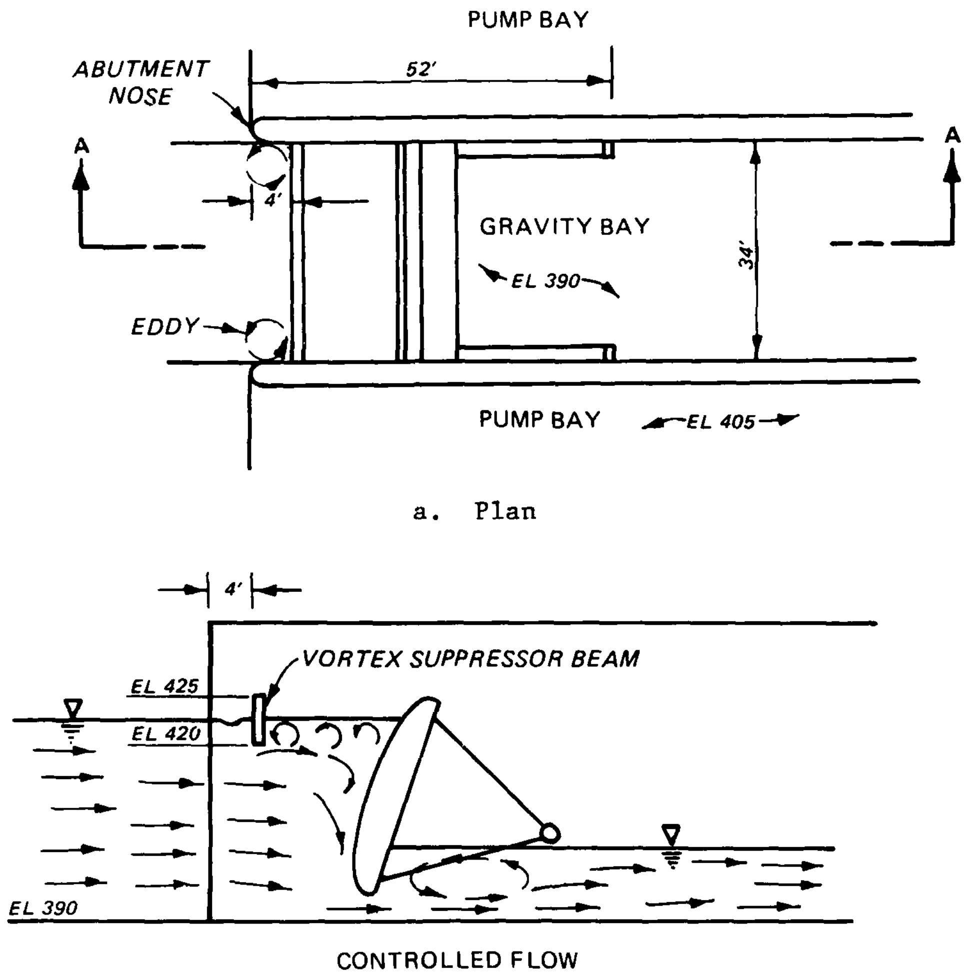
39. The type 3 gravity flow control structure performed satisfactorily



a. Elevation

b. Plan

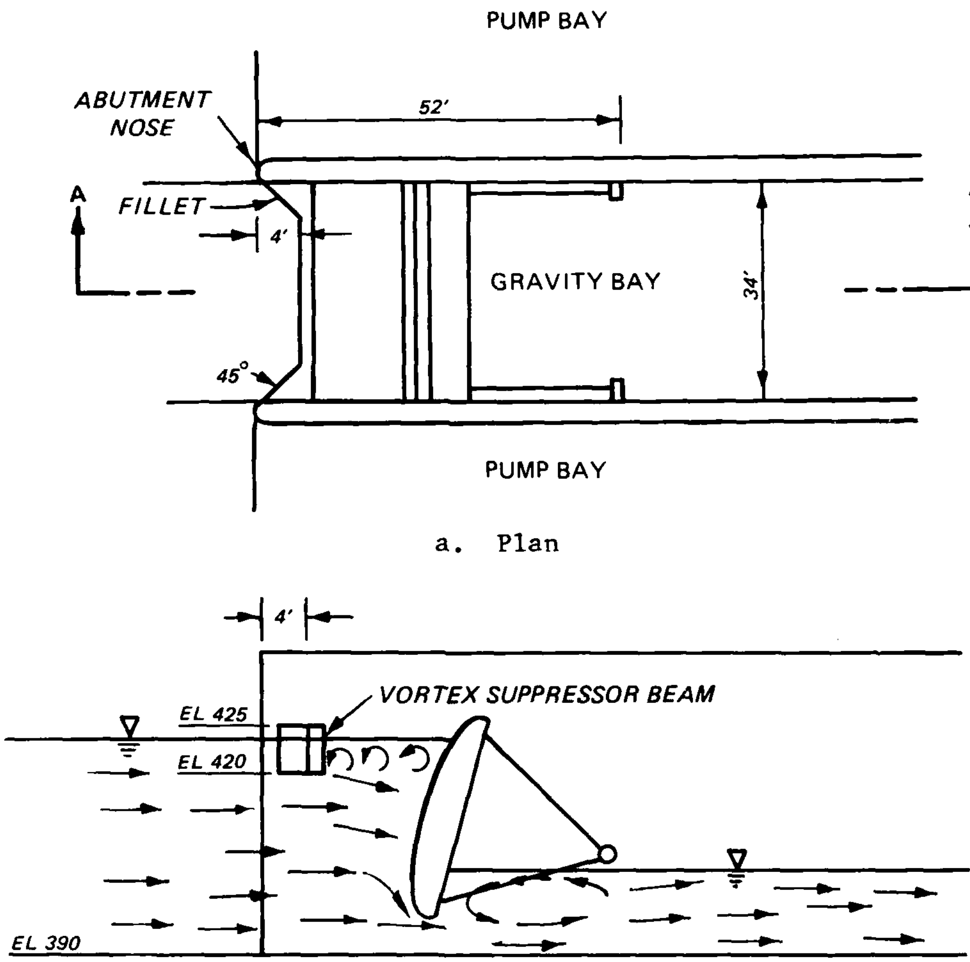
Figure 14. Pump location, Scheme C type 2 suction bell



a. Plan

b. Section A-A

Figure 15. Scheme C type 2 gravity control



a. Plan

b. Section A-A

Figure 16. Scheme C type 3 gravity control

for all controlled flows (submerged and unsubmerged) but was unsatisfactory for uncontrolled flows above 15,000 cfs. With uncontrolled flows above 15,000 cfs the vortex suppressor intersected the nappe as shown in Figure 17. The vortex suppressor beam was moved downstream to a position where the beam did not interfere with uncontrolled flow. However, moving the beam downstream reduced its effectiveness in preventing vortices.

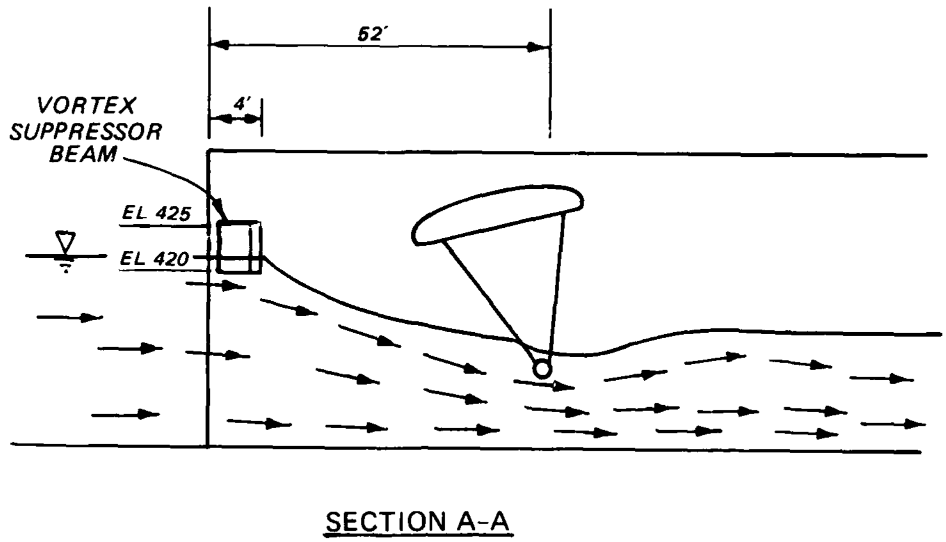


Figure 17. Uncontrolled flow, Scheme C type 3 gravity control

40. The vortex suppressor was removed and the tainter gate was moved 10 ft downstream (type 4) as shown in Figure 18. Moving the tainter gate 10 ft downstream reduced the frequency and intensity of the vortices

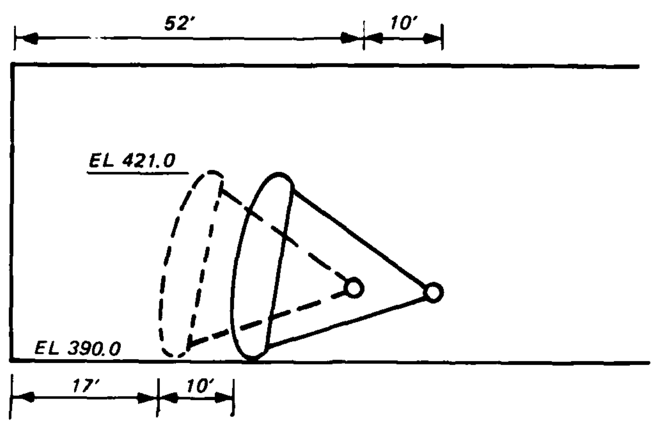


Figure 18. Scheme C type 4 gravity control, tainter gate moved 10 ft downstream

(Photo 11). There was no random or periodic surging of flow on the upstream side of the gate. Tests indicated that the vortex suppressor beam and fillets were needed to eliminate the vortices. Various positioned and sized vortex suppressor beams with fillets were investigated, and the model results indicated that a 5-ft-high beam with fillets located 7 ft downstream from the nose of the abutments (type 5) (Figure 19 and Photo 12) provided satisfactory performance for all anticipated controlled flow conditions. The vortex suppressor beam was also effective in preventing floating debris from passing through the structure with gate openings less than 5 ft. Higher gate openings permitted flow to pull the debris beneath the vortex suppressor beam (Photo 13).

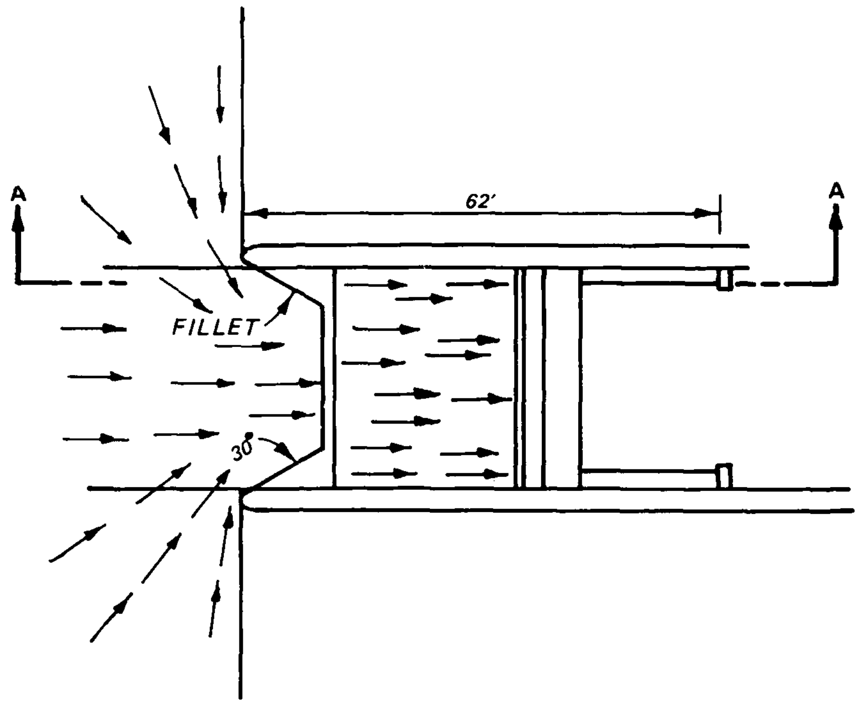
41. Controlled flow rating curves are plotted in Figure 20. Basic discharge calibration data obtained with the model are tabulated in Table 6. An equation for free controlled flow was developed by plotting discharge versus head on the center of the gate opening (Figure 21) and then plotting the values of C_g versus gate opening as shown in Figure 22. The following equation describes the relations between discharge Q, length of gate L, gate opening G_o, and head on the center of the gate opening H_g,

$$Q = 0.866LG_o^{0.87}\left(2gH_g\right)^{0.5} \tag{1}$$

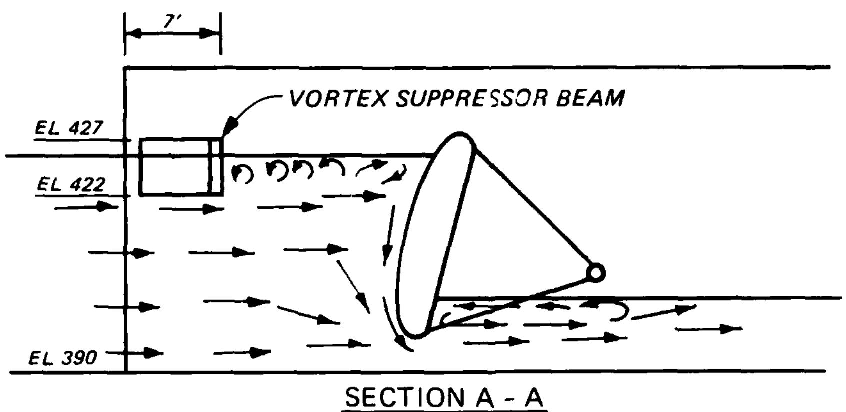
where g is the acceleration due to gravity. Controlled flows entering the Scheme C type 5 gravity flow bay were considered satisfactory for all anticipated operating conditions.

42. Uncontrolled flow. With the design uncontrolled discharge of 17,000 cfs, the gravity flow control structure produced flow contractions that induced a water-surface drawdown of 4 ft (vertical) at each abutment (Photo 14 and Plate 27). Water-surface profiles along the sidewall and center line of the gravity flow control structure measured with the design discharge of 17,000 cfs and headwater and tailwater at el 422.0 and 414.5, respectively, are shown in Plate 27. Flow control occurred at the entrance of the structure. Discharge rating curves for the gravity flow control structure are provided in Figures 20 and 23. The following equation can be used to compute discharge with uncontrolled free flow.

$$Q = 2.09LH_e^{1.59} \tag{2}$$



a. Plan



b. Section A-A

Figure 19. Controlled flow, Scheme C type 5 gravity control

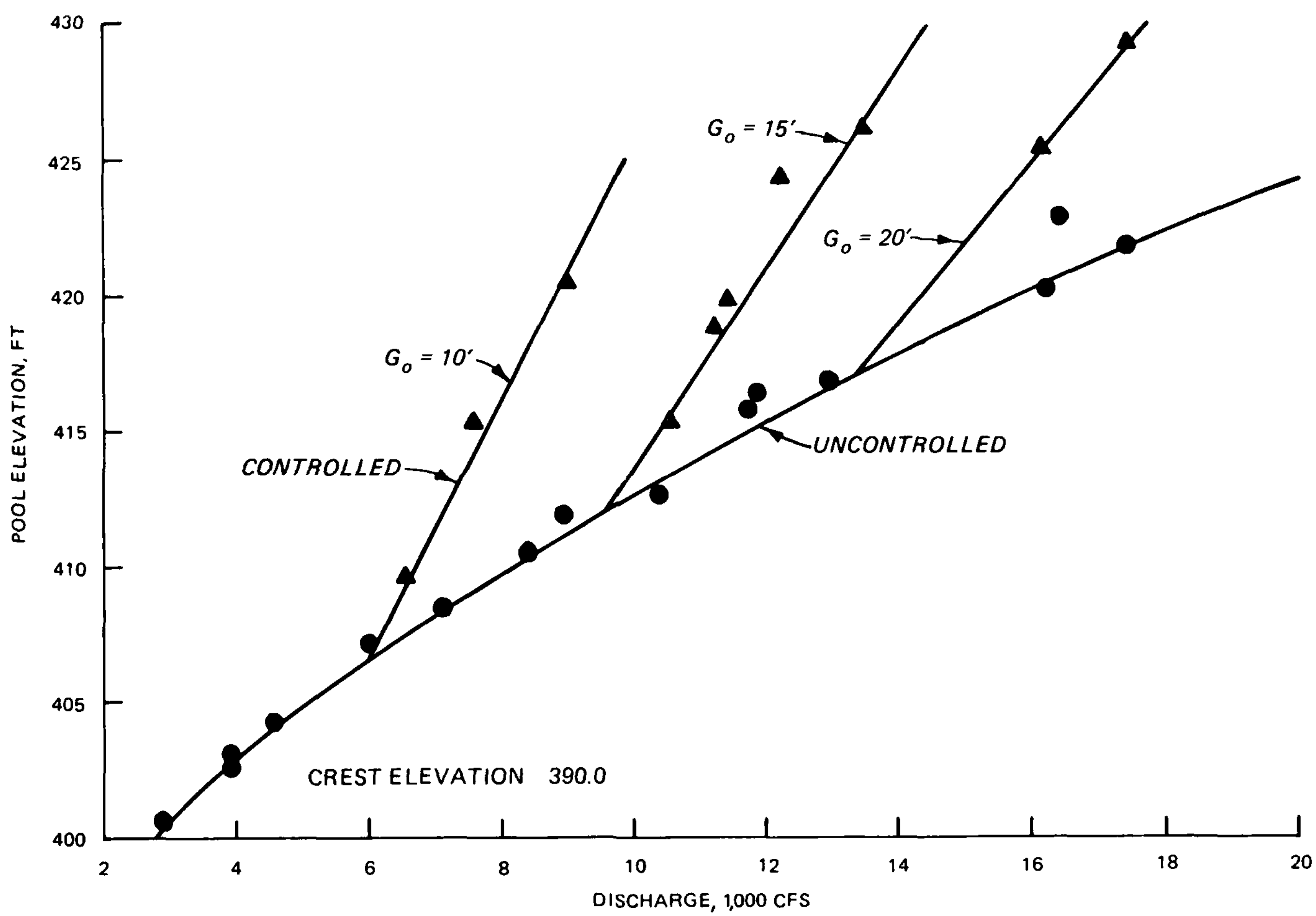
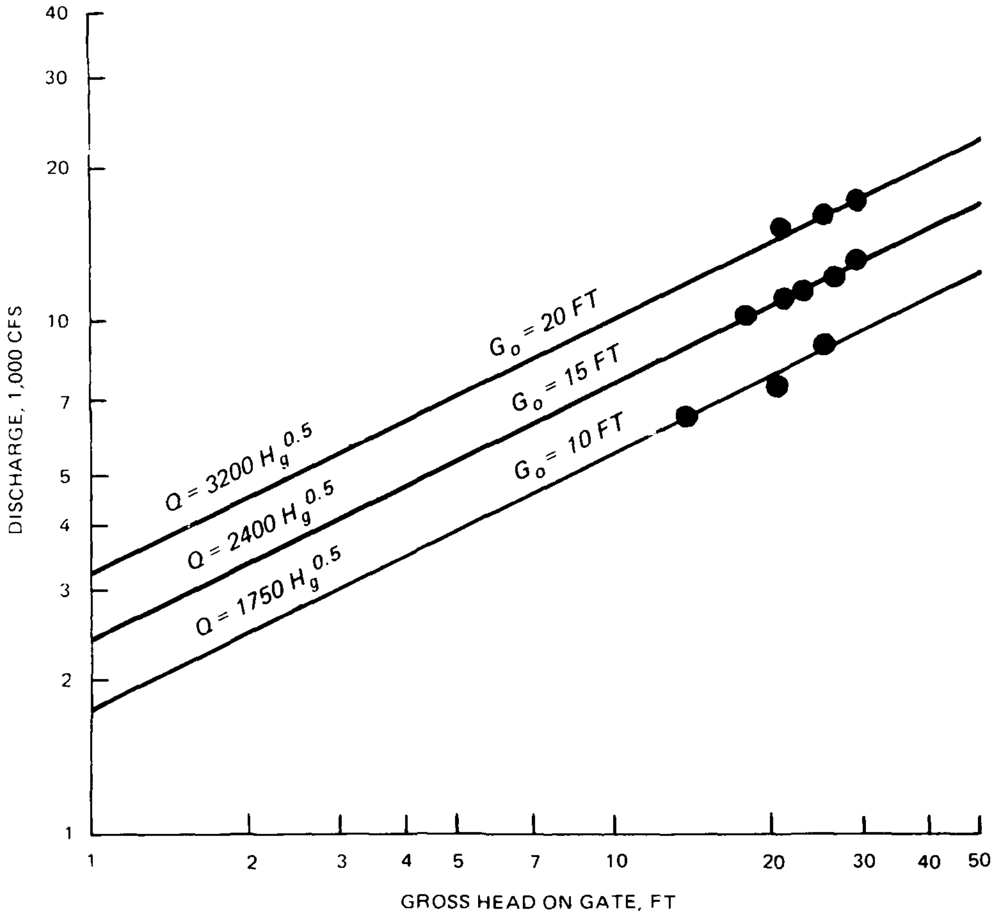


Figure 20. Uncontrolled and controlled discharge rating curves, Scheme C type 5 gravity flow



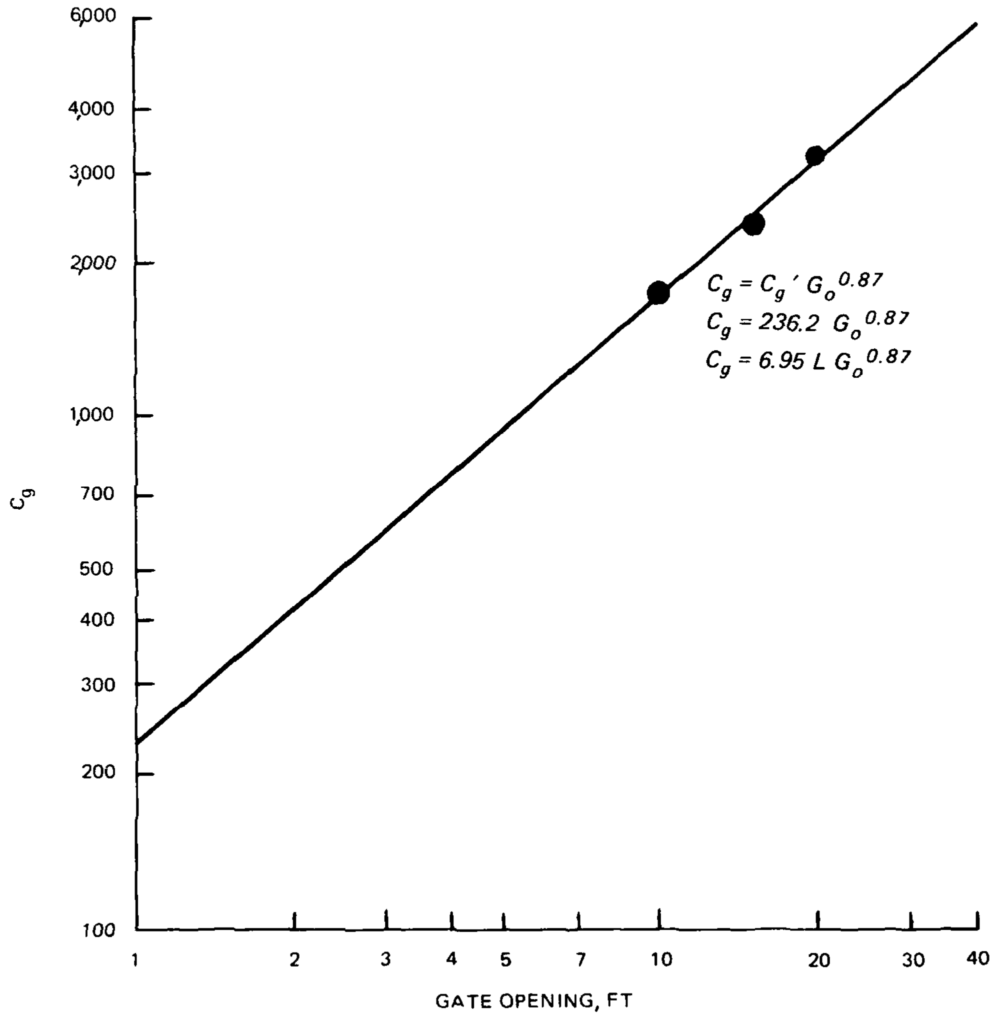
$Q = C_g\ H_g^{0.5}$

Q DISCHARGE, CFS

C_g FUNCTION OF DISCHARGE AND HEAD ON THE CREST

H_g HEAD ON CENTER LINE OF GATE OPENING, FT, COMPUTED BY $H_e - G_o/2$, WHERE H_e IS THE GROSS HEAD ON THE WEIR, FT

Figure 21. Discharge versus gross head on crest, controlled flow, Scheme C type 5 gravity flow



$C_g = C_g' \, G_o^{0.87} = 6.95 \, L \, G_o^{0.87}$

C_g = FUNCTION OF DISCHARGE AND HEAD ON THE GATE

C_g' = FUNCTION OF C_g AND GATE OPENING

G_o = GATE OPENING

L = LENGTH OF GATE, FT (34 FT)

H_g = HEAD ON CENTER LINE OF GATE OPENING, FT

Figure 22. C_g versus gate opening, controlled flow, Scheme C type 5 gravity flow

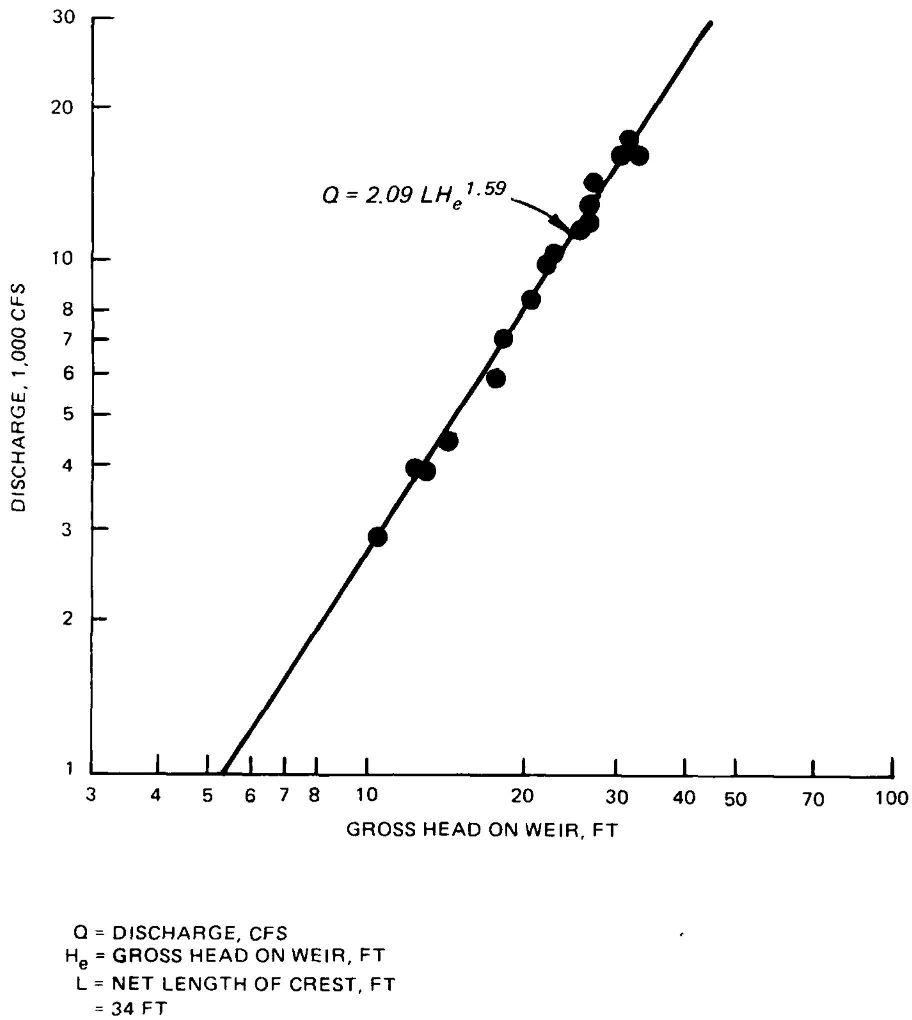


Figure 23. Discharge-head relation for free uncontrolled flow, Scheme C type 5 gravity flow

where H_e is the gross head on the weir. Basic discharge data obtained with the model are tabulated in Table 6. Uncontrolled flows entering the gravity flow control structure were considered satisfactory for all anticipated discharges.

Stilling basin

43. A tailwater rating curve provided by the Louisville District is shown in Figure 24. This curve was used to set the tailwater elevations for various discharges during tests of the stilling basin. The baffle blocks of the Scheme C type 1 design stilling basin (Plate 28) did not provide sufficient resistance and permitted an unstable and oblique hydraulic jump on the surface with eddies in the stilling basin at a discharge of 17,000 cfs

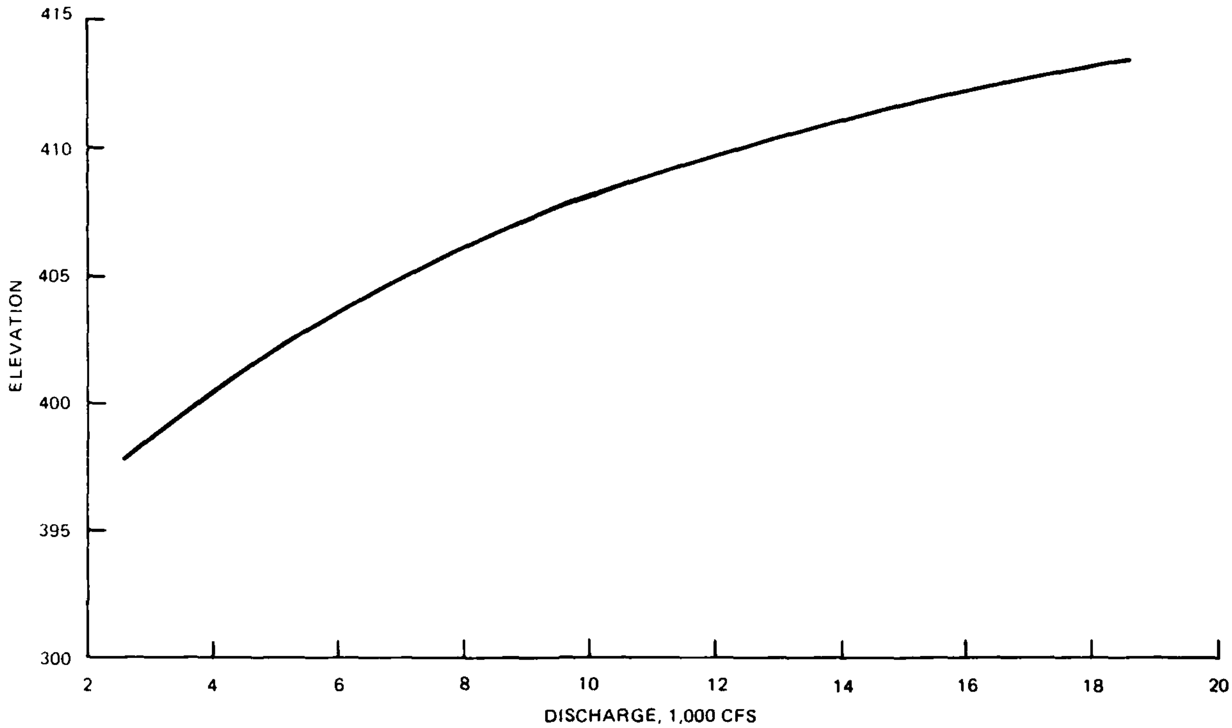


Figure 24. Tailwater rating curve, Scheme C gravity flow

(uncontrolled flow) and minimum tailwater at el 412.5 (Plate 28). Discharges from 3,000 to 17,000 cfs (uncontrolled and controlled) induced flow separation along the sidewalls in the flared section and generated eddies in the stilling basin (Plate 28) due to the unstable and oblique hydraulic jump induced in the chute upstream of the stilling basin.

44. The baffle blocks were increased in height from 4 to 10 ft (Scheme C type 2 stilling basin) as shown in Plate 29. This provided more resistance and stability for the hydraulic jump and reduced, but did not eliminate, the eddy action. The rate of sidewall flare was decreased from 1V on 3H to 1V on 5.5H (type 3 design stilling basin) and 1V on 10H (type 4 design stilling basin) as shown in Plates 30 and 31, respectively. The model indicated that both 1V on 5.5H and 1V on 10H sidewall flares reduced the tendency for flow separation along the sidewalls and formation of eddies in the stilling basin. However, for some flow conditions, there were tendencies for an unstable and oblique hydraulic jump to form on the surface in the chute upstream of the stilling basin, uneven flow distribution, and occasional adverse eddies in the stilling basin. The parabolic drop and stilling basin baffles were moved upstream (type 5 design stilling basin shown in Plate 32), and

satisfactory hydraulic performance was observed for all anticipated flow conditions. However, the type 5 design stilling basin was considered unsatisfactory by the Louisville District due to increased construction costs.

45. The type 6 design stilling basin, which was the design adopted for use, was formed by sloping the invert of the chute from el 390.0 to 386.0 and locating the 10-ft-high baffles 55 ft from the toe of the slope as shown in Plate 33. The baffles were located various distances from the toe of the slope, and a distance of 55 ft provided the best hydraulic performance. Current patterns, maximum wave amplitude, and bottom velocities are also shown in Plate 33. The type 6 design stilling basin provided a stable hydraulic jump and prevented the formation of adverse eddies in the stilling basin. Various flow conditions are shown in Photo 15. The pier in the middle of the gravity section (Photo 15) generates turbulence which is dissipated in the stilling basin.

Riprap

46. Approach channel riprap (Figure 12 and Plate 20) with a d_{50} of 6 in. upstream from a 20-ft paved section as developed with Scheme A was stable for all pumped or gravity flow discharges including the design gravity flow of 17,000 cfs.

47. Exit channel riprap with a d_{50} of 6 in. failed from the end of the stilling basin to a point 10 ft downstream during a discharge of 17,000 cfs and tailwater at el 412.5. The type 2 design riprap was composed of stone with a d_{50} of 8 in. for a distance of 25 ft downstream from the stilling basin (Plate 33), followed with stone having a d_{50} of 6 in. No failure of the type 2 design riprap was observed after it was subjected to anticipated flows as great as 17,000 cfs and tailwater at el 412.5 for a period of 2 hr (prototype).

PART IV: DISCUSSION AND CONCLUSIONS

48. Initially, the sump and the gravity flow outlet were designed to be separate structures. Model tests indicated satisfactory sump performance during operation of any combination of the five pumps. However, the gravity control structure required an expensive wing wall design to prevent vortices in the approach during major floods.

49. The sump and gravity control structures were combined by locating the gravity control below the sump (Scheme A, Photo 1). During operation of the pumps, unsymmetrical current distribution in the approach induced several surface vortices in the sump. A false backwall and a vortex suppressor beam were effective in eliminating surface vortices. A pier located in the center of each pump bay for structural purposes did not adversely affect sump performance.

50. The Scheme A gravity flow outlet was located below the sump and included a self-regulating tainter gate (autogate) designed to maintain the recreation pool within 3 ft of pool el 421.0 (Plate 11). When the pool level exceeded el 424.0, the roller gates were opened, providing twin 15- by 15-ft conduits. Submerged flow through the gravity bay generated turbulence and waves 1 ft high near the autogate. The autogate was moved upstream of the roller gates to provide better access for maintenance and operation.

51. Subsequent value engineering studies by the Louisville District indicated that it would be cost effective to reduce the number of pumps from six to four (Scheme B). The gravity flow outlet was not changed and the hydraulic performance of the gravity flow outlet was not affected. Performance of the Scheme B sump was considered satisfactory.

52. Engineers from the Louisville District decided, based on additional value engineering studies, that a single tainter gate (Scheme C, the adopted design, shown in Plate 20) would increase the capacity of the gravity flow and reduce the structural costs. The total pumping capacity of the Scheme C design remained 4,100 cfs and the capacity of the gravity bay was increased to 17,000 cfs. The Scheme C sump performed satisfactorily for any combination of pumps operating and anticipated flow conditions.

53. Approach flows to the Scheme C gravity control were satisfactory. For all controlled flows greater than 1,300 cfs, an air-entraining surface vortex developed upstream and on each side of the tainter gate. The vortices

were eliminated by a vortex suppressor beam located upstream from the tainter gate. The vortex suppressor beam was also effective in preventing floating debris from passing through the structure with gate openings less than 5 ft. Higher gate openings permitted flow to pull the debris beneath the beam. Controlled and uncontrolled discharge rating curves were developed from the model.

54. The initial design of the Scheme C stilling basin permitted an unstable and oblique hydraulic jump in the stilling basin at a discharge of 17,000 cfs. Discharges from 3,000 to 17,000 cfs (uncontrolled and controlled) induced flow separation along the sidewalls in the flared section and generated eddies in the stilling basin. Increasing the baffle block height from 4 to 10 ft provided more resistance and stability for the hydraulic jump but did not eliminate all eddy action. Satisfactory stilling basin performance was obtained by decreasing the rate of sidewall flare, sloping the invert of the chute from the outlet to the stilling basin apron, and locating the 10-ft-high baffles 55 ft from the toe of the slope (Scheme C type 6 stilling basin, shown in Plate 33). Riprap in the exit channel was stable for all anticipated flow conditions.

Table 1

Pressure Fluctuation, Swirl, and Stages of Vortex Development

Scheme A Type 1 Sump

Water-Surface El	Sump Performance Indicator*	Pump No. 1	2	3	4	5	6
421.0	Pressure fluctuation, ft	1.0	X	X	X	X	X
	Swirl, rpm	1.0←					
	Stage of vortex development	(E)					
421.0	Pressure fluctuation, ft	X	X	2.0	1.5	X	X
	Swirl, rpm			1.0←	1.0→		
	Stage of vortex development			(D)	(C)		
421.0	Pressure fluctuation, ft	X	X	X	5.0	2.0	2.0
	Swirl, rpm				6.0←	1.0←	2.0→
	Stage of vortex development				(B)	(C)	(D)
421.0	Pressure fluctuation, ft	1.0	1.0	5.0	X	X	X
	Swirl, rpm	1.0←	2.0→	7.0→			
	Stage of vortex development	(D)	(C)	(B)			
421.0	Pressure fluctuation, ft	1.0	1.0	1.0	1.0	1.0	1.0
	Swirl, rpm	2.0←	1.0→	1.0→	1.0←	1.0←	1.0←
	Stage of vortex development	(B)	(D)	(D)	(D)	(D)	(E)
426.0	Pressure fluctuation, ft	X	X	X	2.0	1.0	1.0
	Swirl, rpm				7.0←	1.0←	2.0→
	Stage of vortex development				(A)	(A)	(A)
426.0	Pressure fluctuation, ft	1.0	1.0	1.0	1.0	1.0	1.0
	Swirl, rpm	1.0→	1.0←	1.0←	1.0→	1.0→	1.0→
	Stage of vortex development	(A)	(A)	(A)	(A)	(A)	(A)
432.0	Pressure fluctuation, ft	X	X	X	2.0	1.0	1.0
	Swirl, rpm				4.0←	1.0←	2.0←
	Stage of vortex development				(A)	(A)	(A)
432.0	Pressure fluctuation, ft	X	X	X	1.0	X	X
	Swirl, rpm				1.0→		
	Stage of vortex development				(A)		
432.0	Pressure fluctuation, ft	1.0	1.0	1.0	1.0	1.0	1.0
	Swirl, rpm	1.0→	1.0→	1.0←	1.0←	1.0←	1.0→
	Stage of vortex development	(A)	(A)	(A)	(A)	(A)	(A)

Note: All magnitudes are expressed in terms of prototype equivalents.
→ = clockwise rotation.
← = counterclockwise rotation.
X = pump not operating.
Discharge for pumps 1 and 6 = 410 cfs each; for pumps 2, 3, 4, and 5 = 820 cfs each.

* Pressure fluctuations beneath the pump intake are given in feet of water.

Table 2

Pressure Fluctuation, Swirl, and Stages of Vortex Development

Scheme A Type 4 Sump

Water-Surface El	Sump Performance Indicator*	Pump No. 1	2	3	4	5	6
421.0	Pressure fluctuation, ft	1.0	X	X	X	X	X
	Swirl, rpm	1.0←					
	Stage of vortex development	(B)					
421.0	Pressure fluctuation, ft	X	X	1.0	1.0	X	X
	Swirl, rpm			1.0←	1.0→		
	Stage of vortex development			(A)	(B)		
421.0	Pressure fluctuation, ft	X	X	X	2.0	1.0	1.0
	Swirl, rpm				3.0←	2.0←	1.0→
	Stage of vortex development				(B)	(A)	(B)
421.0	Pressure fluctuation, ft	1.0	1.0	1.0	X	X	X
	Swirl, rpm	2.0←	2.0→	3.0→			
	Stage of vortex development	(A)	(A)	(B)			
421.0	Pressure fluctuation, ft	1.0	1.0	1.0	1.0	2.0	1.0
	Swirl, rpm	1.0←	1.0→	1.0→	1.0←	1.0←	1.0→
	Stage of vortex development	(A)	(A)	(A)	(A)	(A)	(A)
426.0	Pressure fluctuation, ft	X	X	X	1.0	1.0	1.0
	Swirl, rpm				1.0←	1.0←	1.0→
	Stage of vortex development				(A)	(A)	(A)
426.0	Pressure fluctuation, ft	1.0	1.0	1.0	1.0	1.0	1.0
	Swirl, rpm	1.0→	1.0→	1.0←	1.0←	1.0←	1.0→
	Stage of vortex development	(A)	(A)	(A)	(A)	(A)	(A)
432.0	Pressure fluctuation, ft	X	X	1.0	1.0	1.0	1.0
	Swirl, rpm				2.0←	1.0←	2.0→
	Stage of vortex development				(A)	(A)	(A)
432.0	Pressure fluctuation, ft	X	X	X	1.0	X	X
	Swirl, rpm				1.0→		
	Stage of vortex development				(A)		
432.0	Pressure fluctuation, ft	1.0	1.0	1.0	1.0	1.0	1.0
	Swirl, rpm	1.0←	1.0→	1.0←	1.0←	1.0←	1.0←
	Stage of vortex development	(A)	(A)	(A)	(A)	(A)	(A)

Note: All magnitudes are expressed in terms of prototype equivalents.
→ = clockwise rotation.
← = counterclockwise rotation.
X = pump not operating.
Discharge for pumps 1 and 6 = 410 cfs each; for pumps 2, 3, 4, and 5 = 820 cfs each.

* Pressure fluctuations beneath the pump intake are given in feet of water.

Table 3

Basic Free-Flow Data

Scheme A Type 3 Gravity Flow

Bulkhead Open		Bulkhead Closed	
Discharge cfs	Pool El	Discharge cfs	Pool El
3,300	400.0	8,400	412.1
4,200	404.1	10,000	416.8
5,500	403.5	11,500	419.3
6,200	405.6	12,600	424.1
7,000	406.8	14,000	426.0
7,300	409.6	15,100	430.0
7,900	413.0	15,300	428.2
8,400	413.8	15,900	432.4
9,000	417.0		
10,000	417.5		
11,200	421.0		
11,500	423.2		
11,700	425.4		
12,100	429.7		
12,200	430.9		
12,600	432.6		

Table 4

Swirl and Stages of Vortex Development

Scheme B Type 1 Sump

Water-Surface El	Sump Performance Indicator	Pump No. 1	2	3	4
421.0	Swirl, rpm	X	X	X	←2.0
	Stage of vortex development				(A)
421.0	Swirl, rpm	X	X	←3.0	←1.0
	Stage of vortex development			(A)	(A)
421.0	Swirl, rpm	X	1.0→	←2.0	←1.0
	Stage of vortex development		(A)	(A)	(A)
421.0	Swirl, rpm	1.0→	2.0→	←2.0	←1.0
	Stage of vortex development	(A)	(A)	(A)	(A)
421.0	Swirl, rpm	X	3.0→	←2.0	X
	Stage of vortex development		(A)	(A)	
426.0	Swirl, rpm	X	X	←1.0	←1.0
	Stage of vortex development			(A)	(A)
426.0	Swirl, rpm	1.0→	1.0→	1.0←	1.0←
	Stage of vortex development	(A)	(A)	(A)	(A)
432.0	Swirl, rpm	X	X	1.0←	1.0←
	Stage of vortex development			(A)	(A)
432.0	Swirl, rpm	→1.0	→1.0	→1.0	←1.0
	Stage of vortex development	(A)	(A)	(A)	(A)

Note: All magnitudes are expressed in terms of prototype equivalents.
→ = clockwise rotation.
← = counterclockwise rotation.
X = pump not operating.
Discharge per pump = 1,025 cfs.

Table 5

Pressure Fluctuation, Swirl, and Stages of Vortex Development

Scheme C Type 1 Sump

Water-Surface El	Sump Performance Indicator*	Pump No. 1	2	3	4
421.0	Pressure fluctuation, ft	X	X	X	1
	Swirl, rpm				→2
	Stage of vortex development				(A)
421.0	Pressure fluctuation, ft	X	X	1	1
	Swirl, rpm			←1	←1
	Stage of vortex development			(A)	(A)
421.0	Pressure fluctuation, ft	X	1	1	1
	Swirl, rpm		←1	→2	→2
	Stage of vortex development		(A)	(A)	(A)
421.0	Pressure fluctuation, ft	1	1	1	1
	Swirl, rpm	→1	→1	→1	→2
	Stage of vortex development	(A)	(A)	(A)	(A)
421.0	Pressure fluctuation, ft	X	1	1	X
	Swirl, rpm		→2	→2	
	Stage of vortex development		(A)	(A)	
426.0	Pressure fluctuation, ft	X	X	1	1
	Swirl, rpm			→2	→2
	Stage of vortex development			None	None
426.0	Pressure fluctuation, ft	1	1	1	1
	Swirl, rpm	→1	←1	→1	→1
	Stage of vortex development	None	None	None	None
432.0	Pressure fluctuation, ft	X	X	1	1
	Swirl, rpm			→1	→1
	Stage of vortex development			None	None
432.0	Pressure fluctuation, ft	1	1	1	1
	Swirl, rpm	→1	→1	←1	→1
	Stage of vortex development	None	None	None	None

Note: All magnitudes are expressed in terms of prototype equivalents.
→ = clockwise rotation.
← = counterclockwise rotation.
X = pump not operating.
Discharge per pump = 1,025 cfs.

* Pressure fluctuations beneath the pump intake are given in feet of water.

Table 6

Gravity Control Calibration Data

Scheme C Type 5 Gravity Flow

Uncontrolled Flow		Controlled Flow		
Discharge cfs	Pool El	Gate Opening ft	Discharge cfs	Pool El
2,900	400.5	10	6,560	408.6
3,960	402.6	10	7,570	415.1
3,960	402.9	10	8,980	420.5
4,500	404.2	15	10,500	415.3
6,000	407.1	15	11,200	418.8
7,100	408.4	15	11,400	419.9
8,400	410.5	15	12,200	424.4
8,900	411.8	15	13,400	426.2
10,400	412.6	20	15,000	420.7
11,700	415.8	20	16,100	425.5
11,800	416.4	20	17,400	429.3
12,900	416.8			
14,200	417.7			
16,200	420.2			
16,400	422.8			
17,400	421.6			

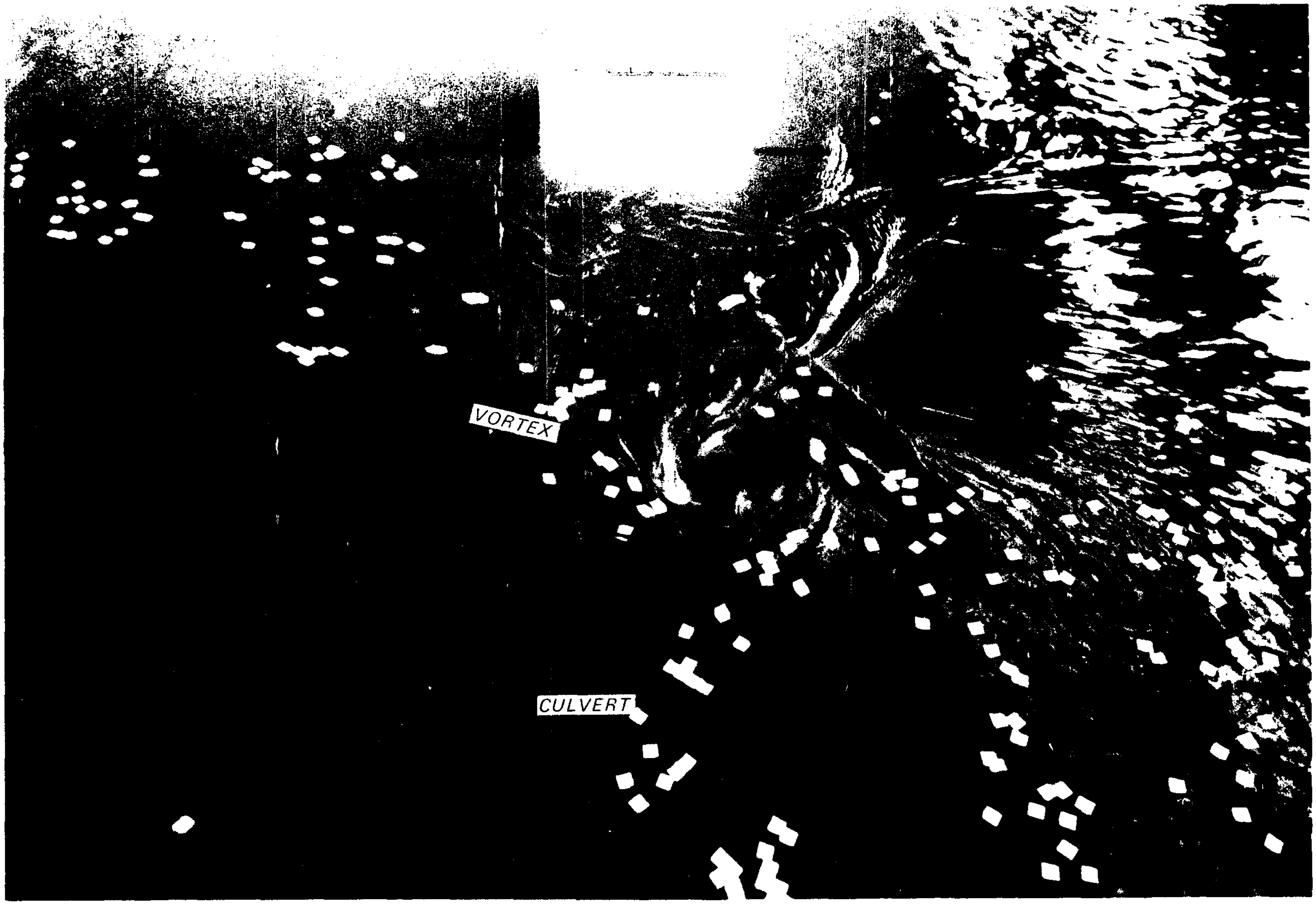
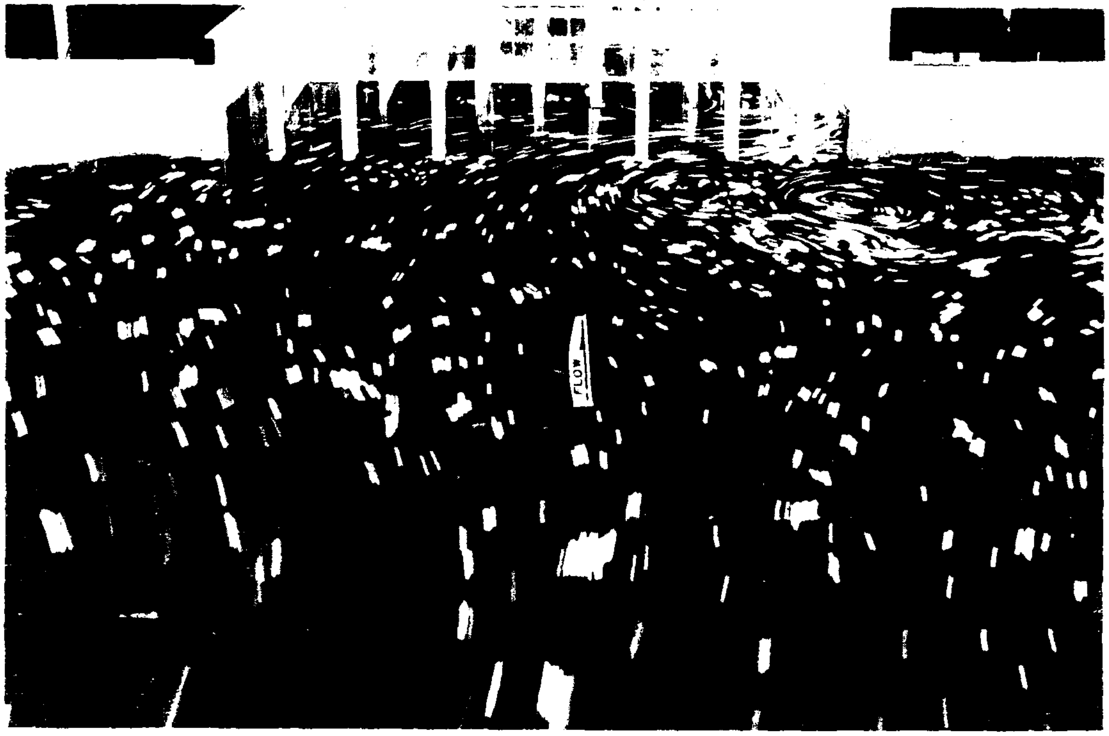
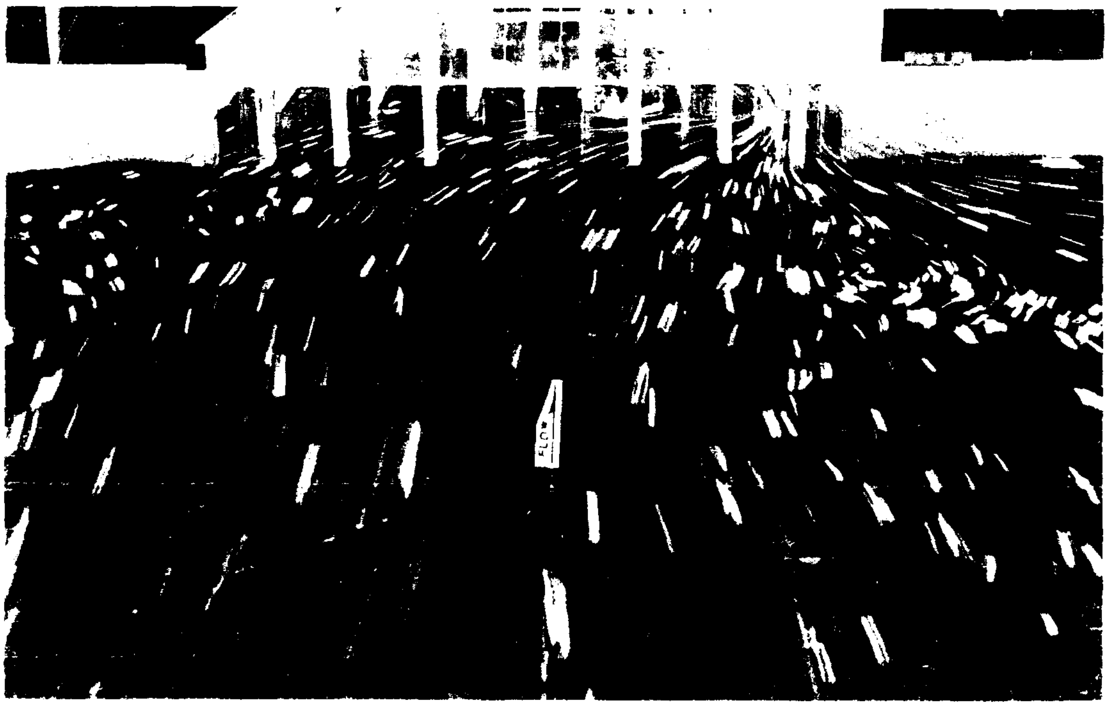


Photo 1. Gravity control intake (original design)

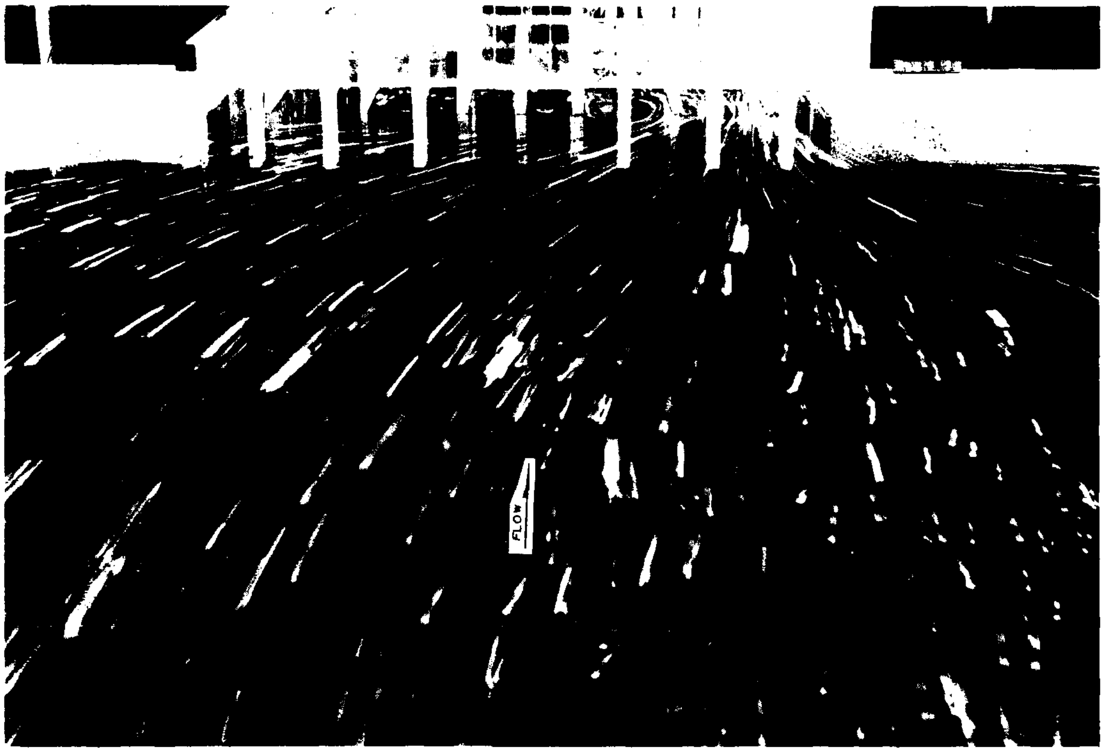


a. Pool el 421.0, pump 6 discharge 410 cfs

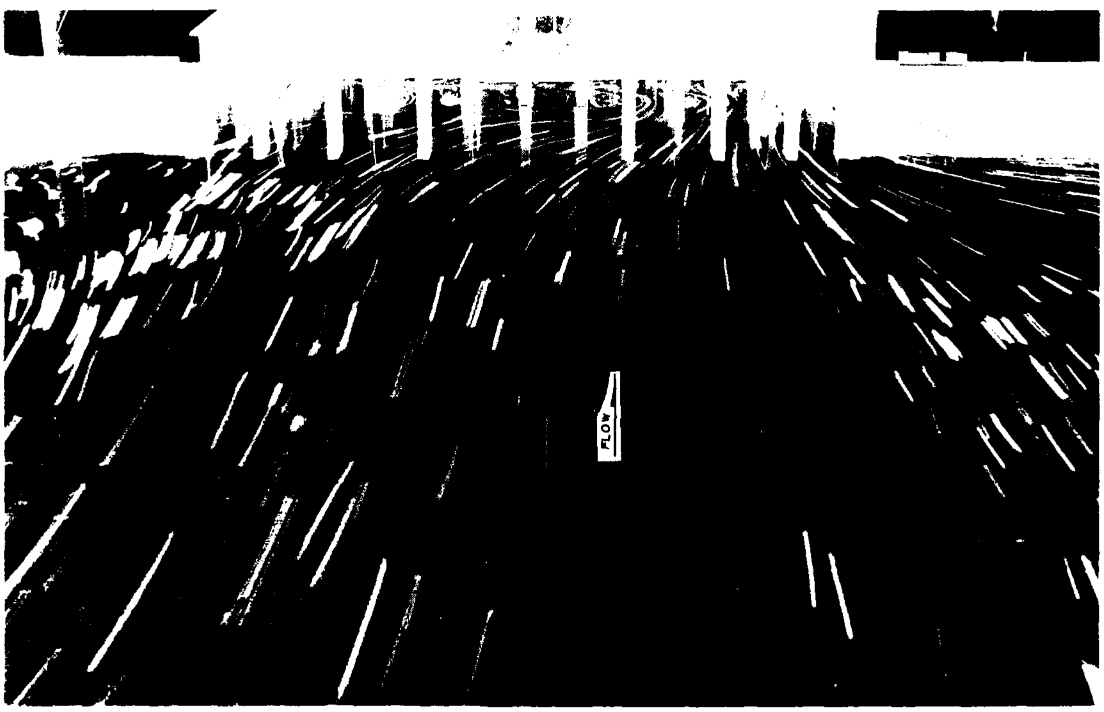


b. Pool el 421.0, pump 5 discharging 820 cfs, pump 6 discharging 410 cfs

[illegible]. Approach currents, Scheme A type 5 sump, exposure time 100 sec (Sheet 1 of 3)

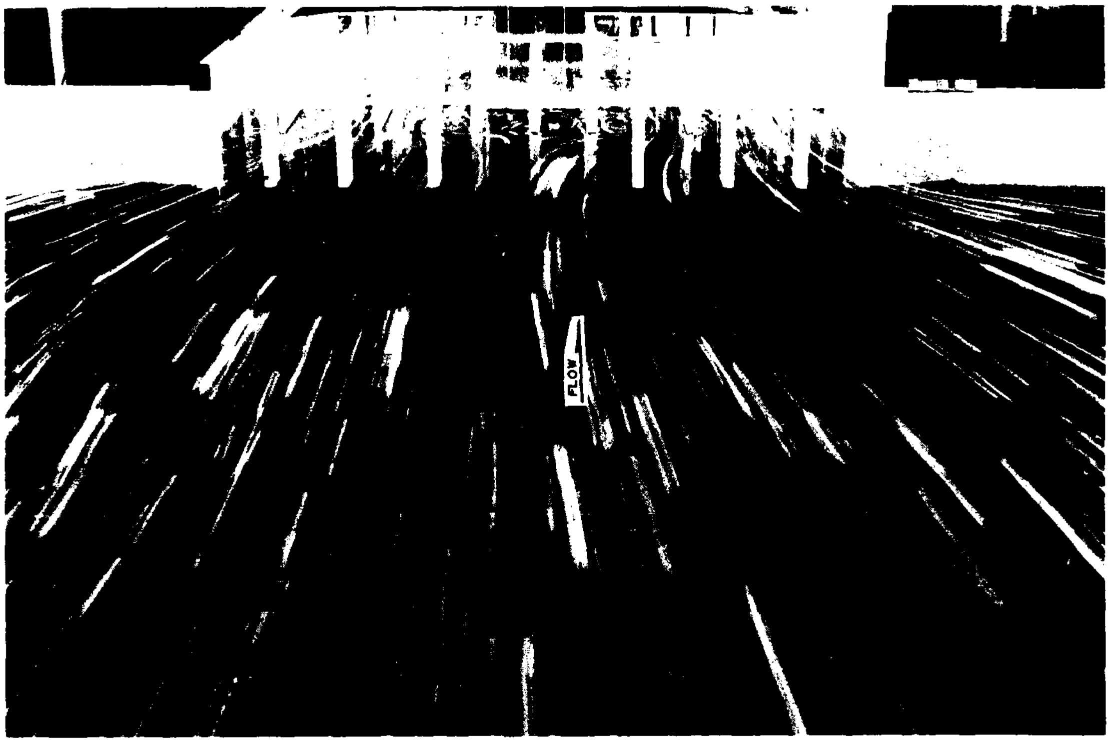


c. Pool el 421.0, pumps 4 and 5 discharging 820 cfs per pump, pump 6 discharging 410 cfs



d. Pool el 421.0, pumps 3, 4, and 5 discharging 820 cfs per pump, pump 6 discharging 410 cfs

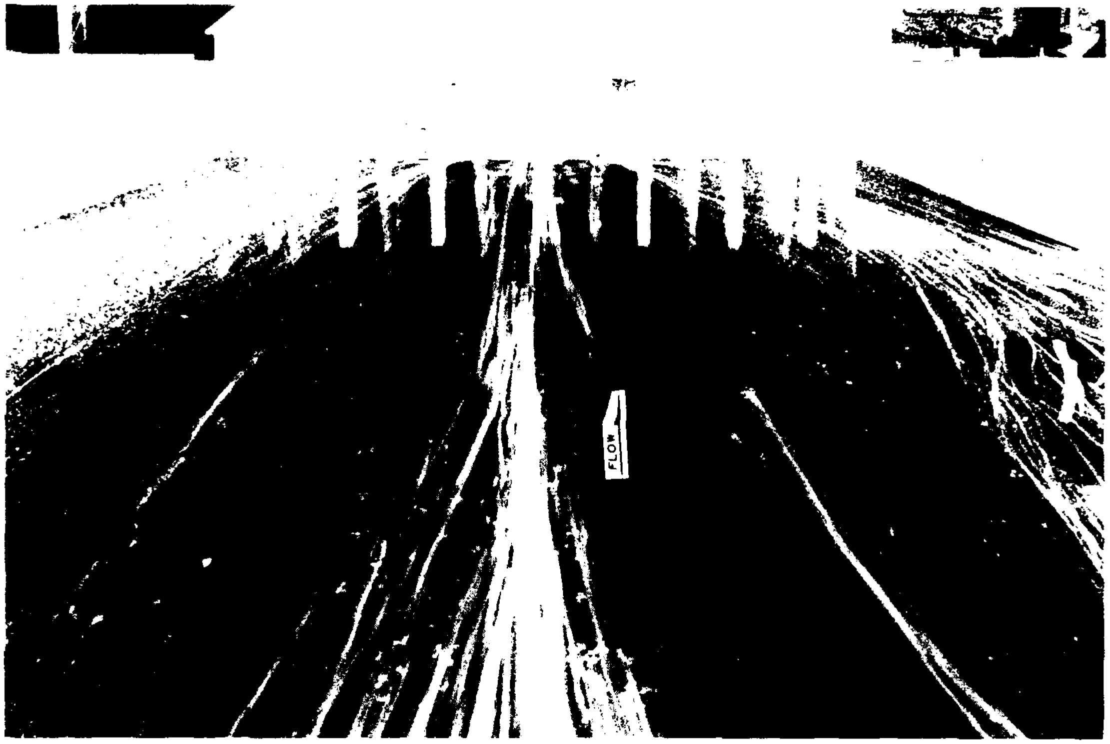
Photo 2. (Sheet 2 of 3)



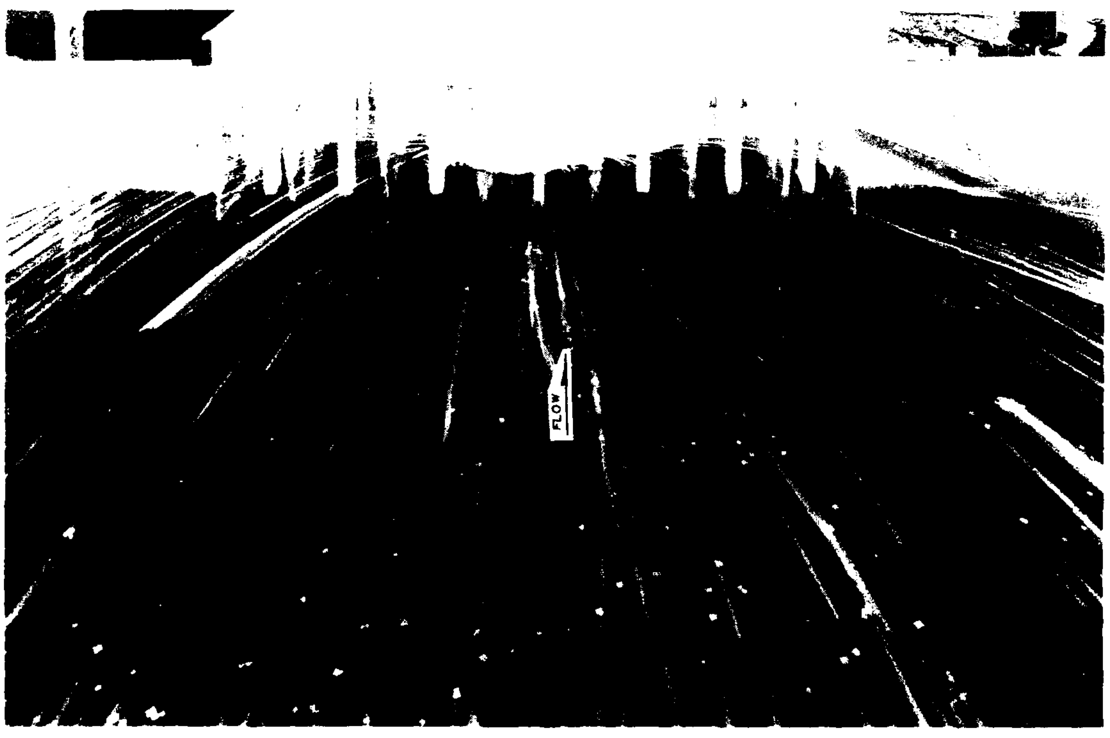
e. Pool el 421.0, pumps 2, 3, 4, and 5 discharging 820 cfs per pump, pumps 1 and 6 discharging 410 cfs per pump

f. Pool el 428.0, pumps 2, 3, 4, and 5 discharging 820 cfs per pump, pumps 1 and 6 discharging 410 cfs per pump

Photo 2. (Sheet 3 of 3)

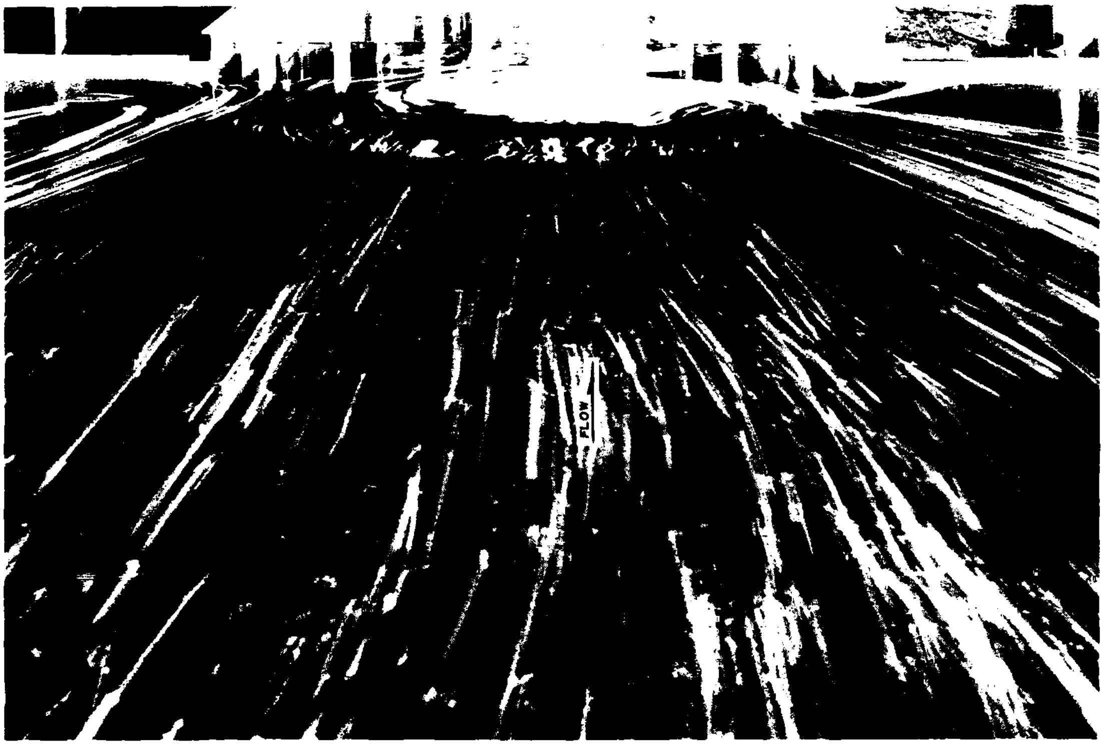


a. Pool el 406.0, tailwater el 399.0, discharge 6,500 cfs



b. Pool el 416.5, tailwater el 408.0, discharge 10,000 cfs

Photo 3. Approach flow, Scheme A type 3 gravity control, exposure time 50 sec (Continued)



c. Pool el 428.0, tailwater el 412.5, discharge 15,000 cfs

Photo 3. (Concluded)

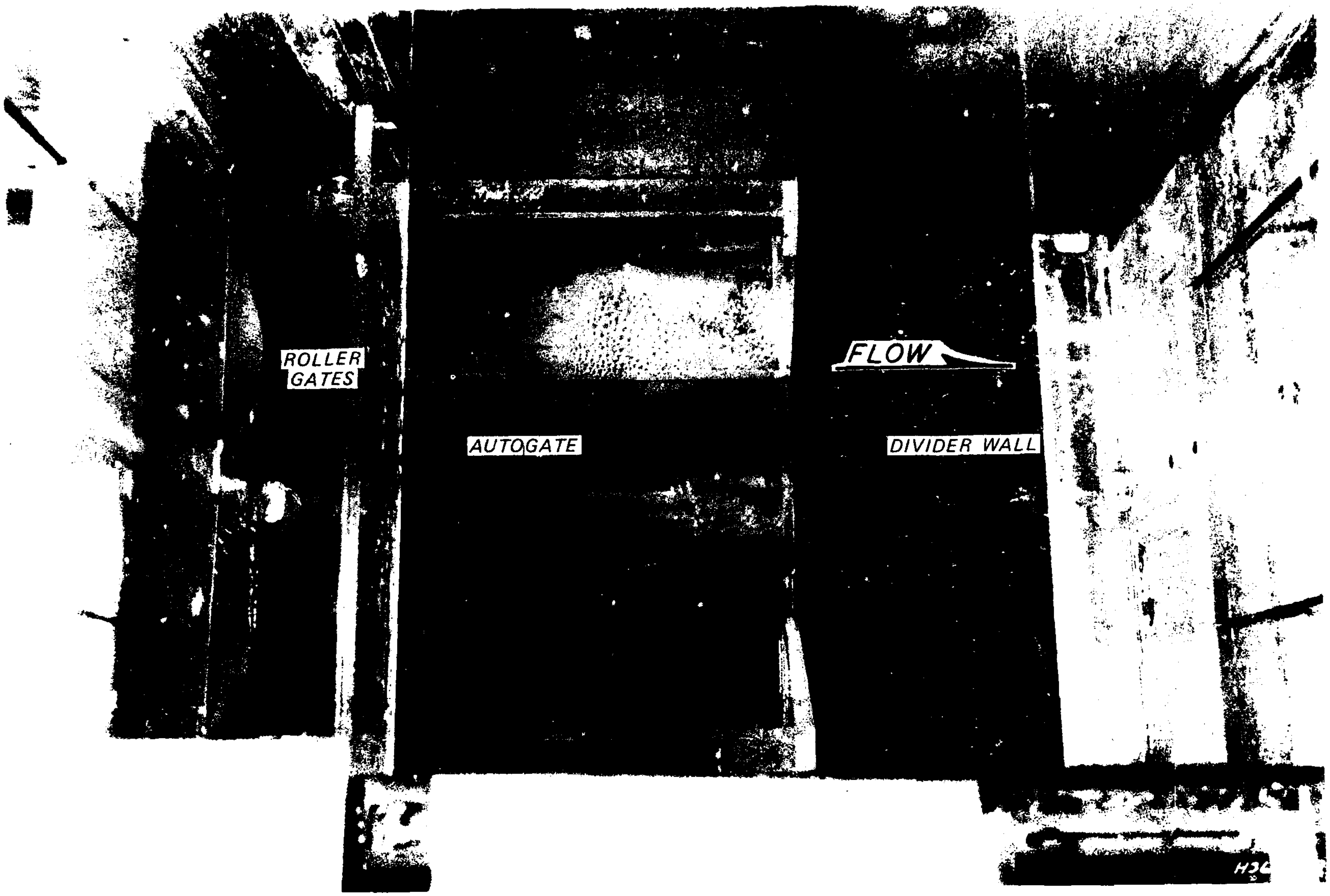


Photo 4. Free-flow conditions, Scheme A type 3 gravity control, roller gates open to el 405.0, discharge 15,000 cfs, pool el 428.0, tailwater el 412.5

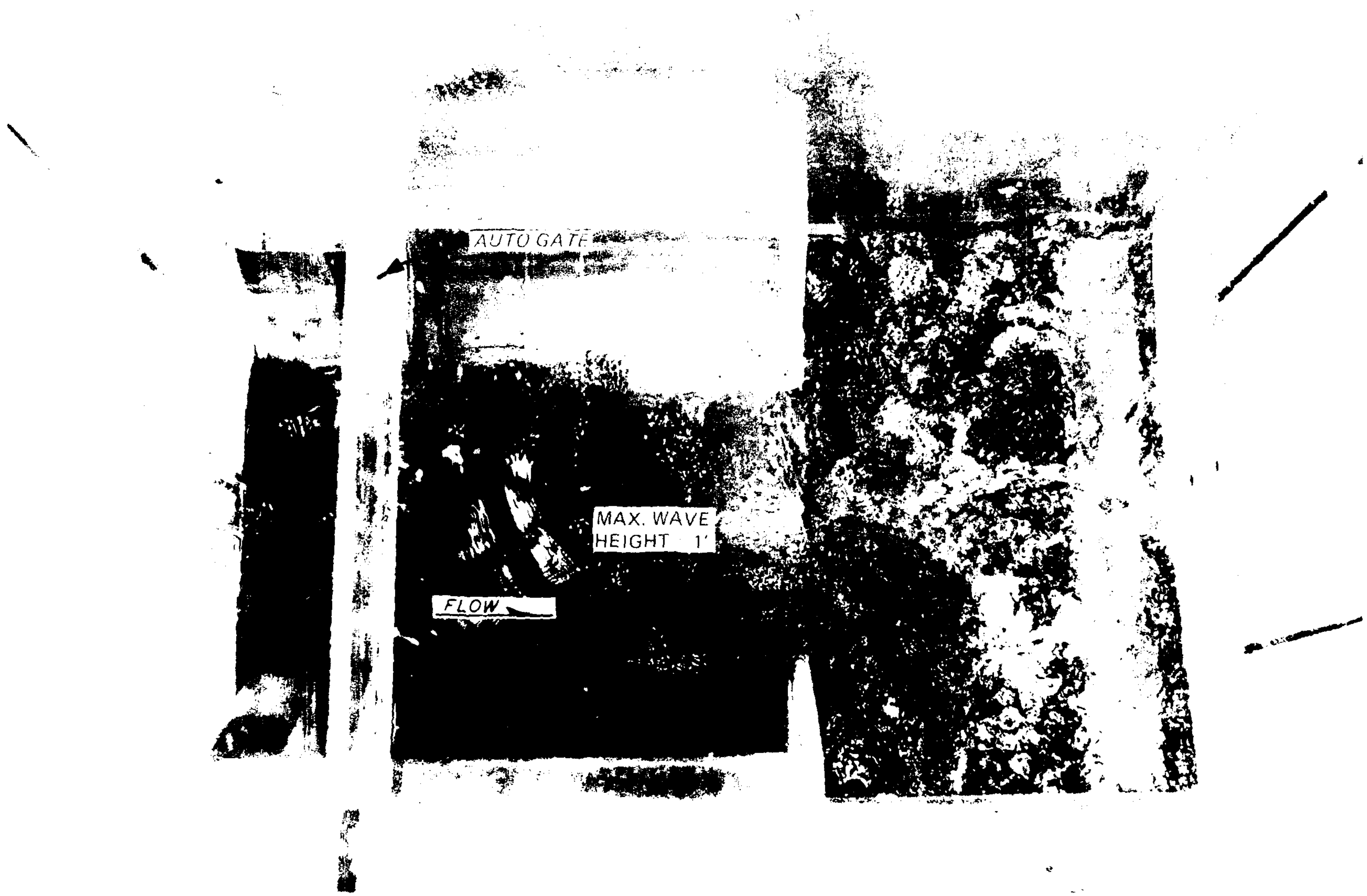


Photo 5. Submerged flow, Scheme A type 3 gravity control, roller gates open, discharge 15,000 cfs, pool el 433.0, tailwater el 417.0

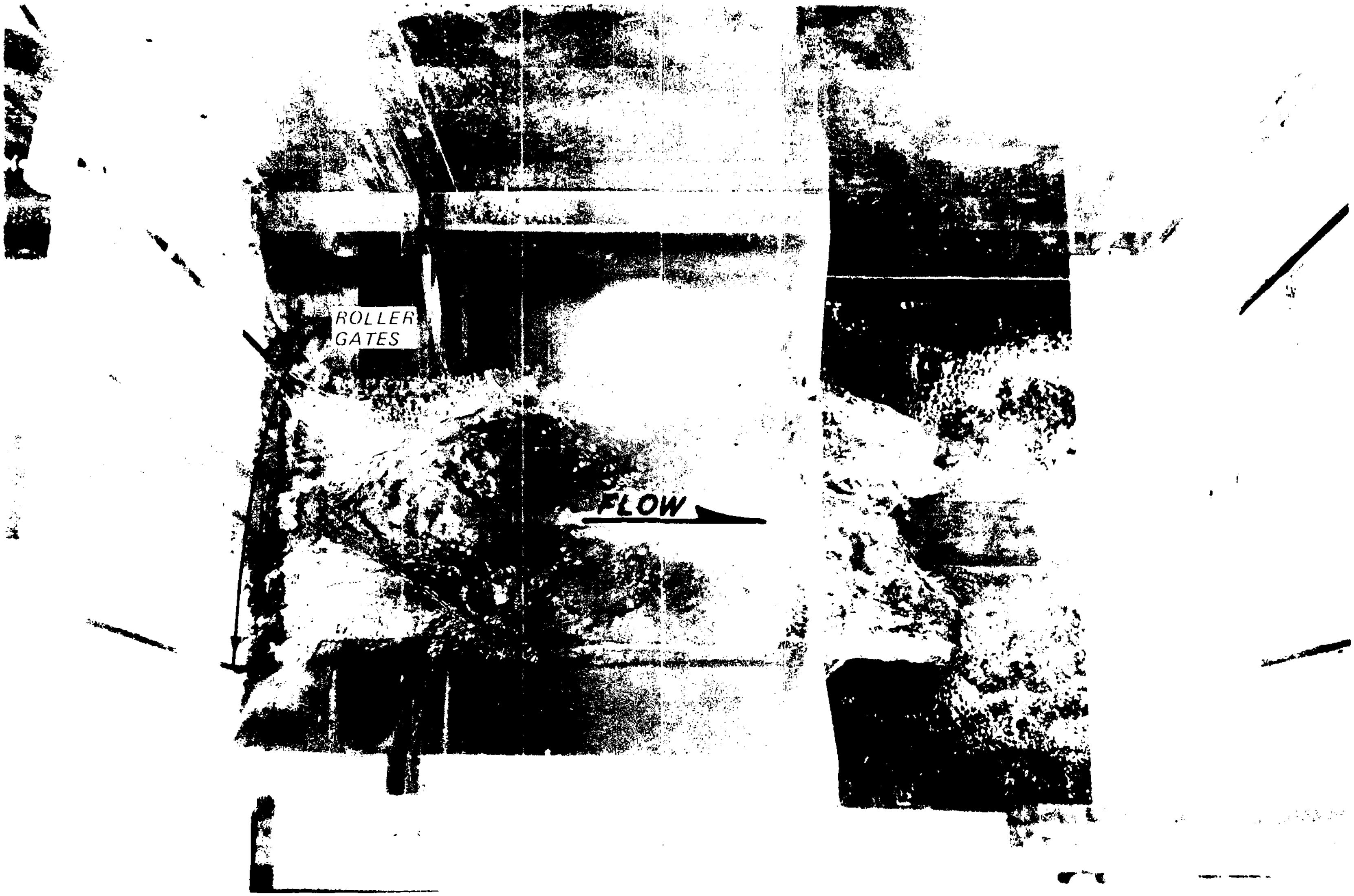
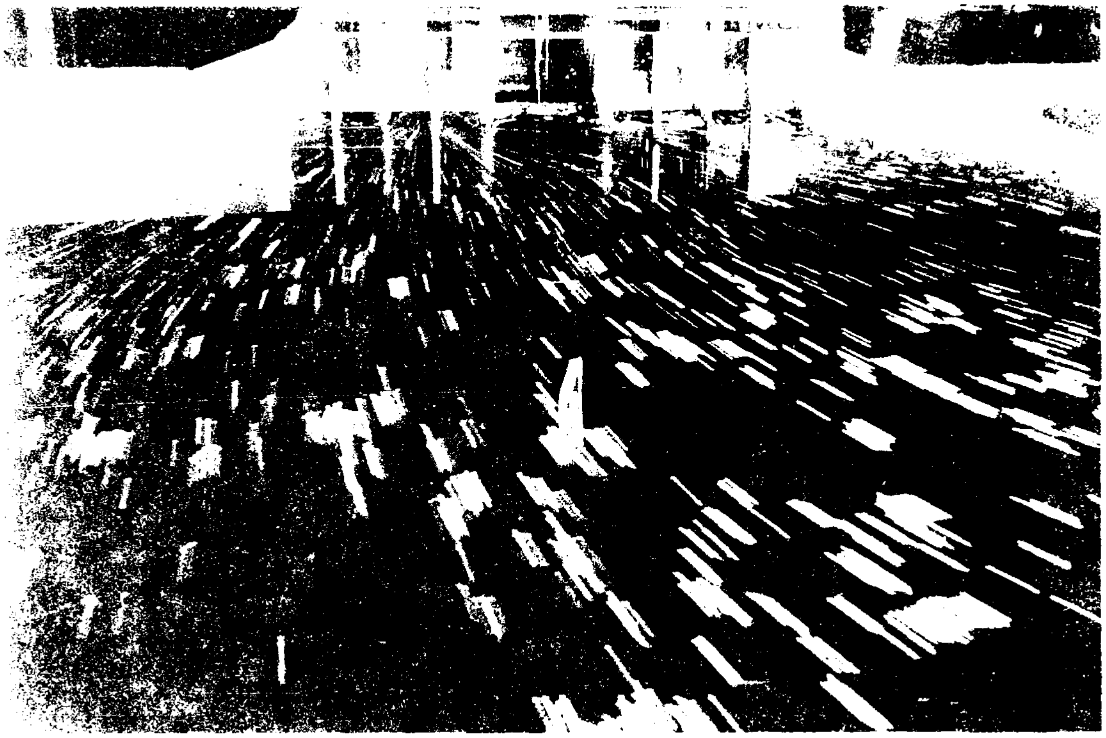
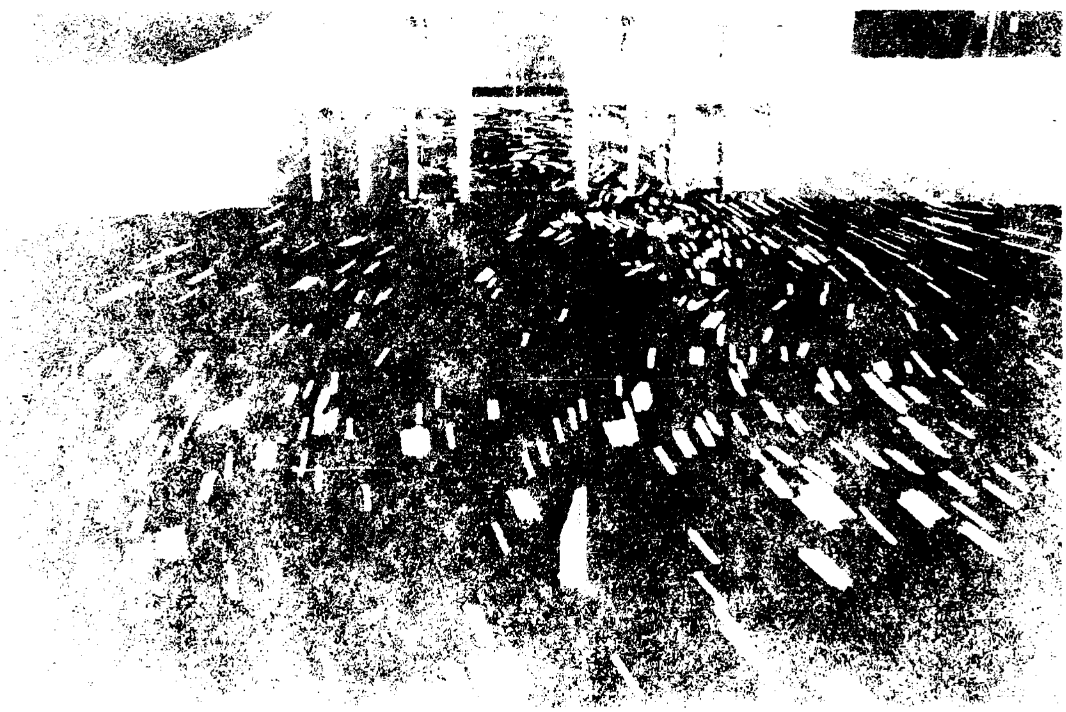


Photo 6. Roller gates closed, Scheme A type 3 gravity control, discharge 2,000 cfs, pool el 421.0, tailwater el 4,000

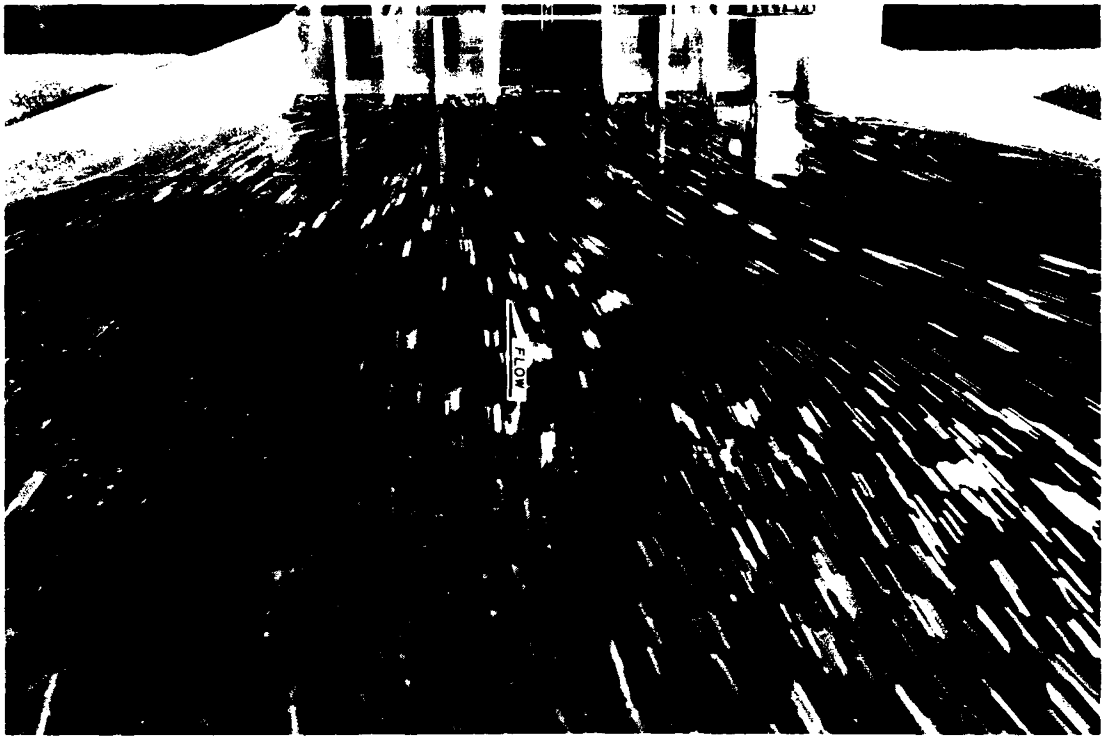


a. Pool el 421.0, pump 2 discharging 1,025 cfs



[illegible] operating, discharge per pump [illegible]

[illegible]



c. Pool el 421.0, pumps 2 and 3 operating, discharge per pump 1,025 cfs

d. Pool el 421.0, pumps 2, 3, and 4 operating, discharge per pump 1,025 cfs

Photo 7. (Concluded)

Photo 8. Scheme C gravity control, discharge 17,000 cfs, pool el 421.3, exposure time 25 sec

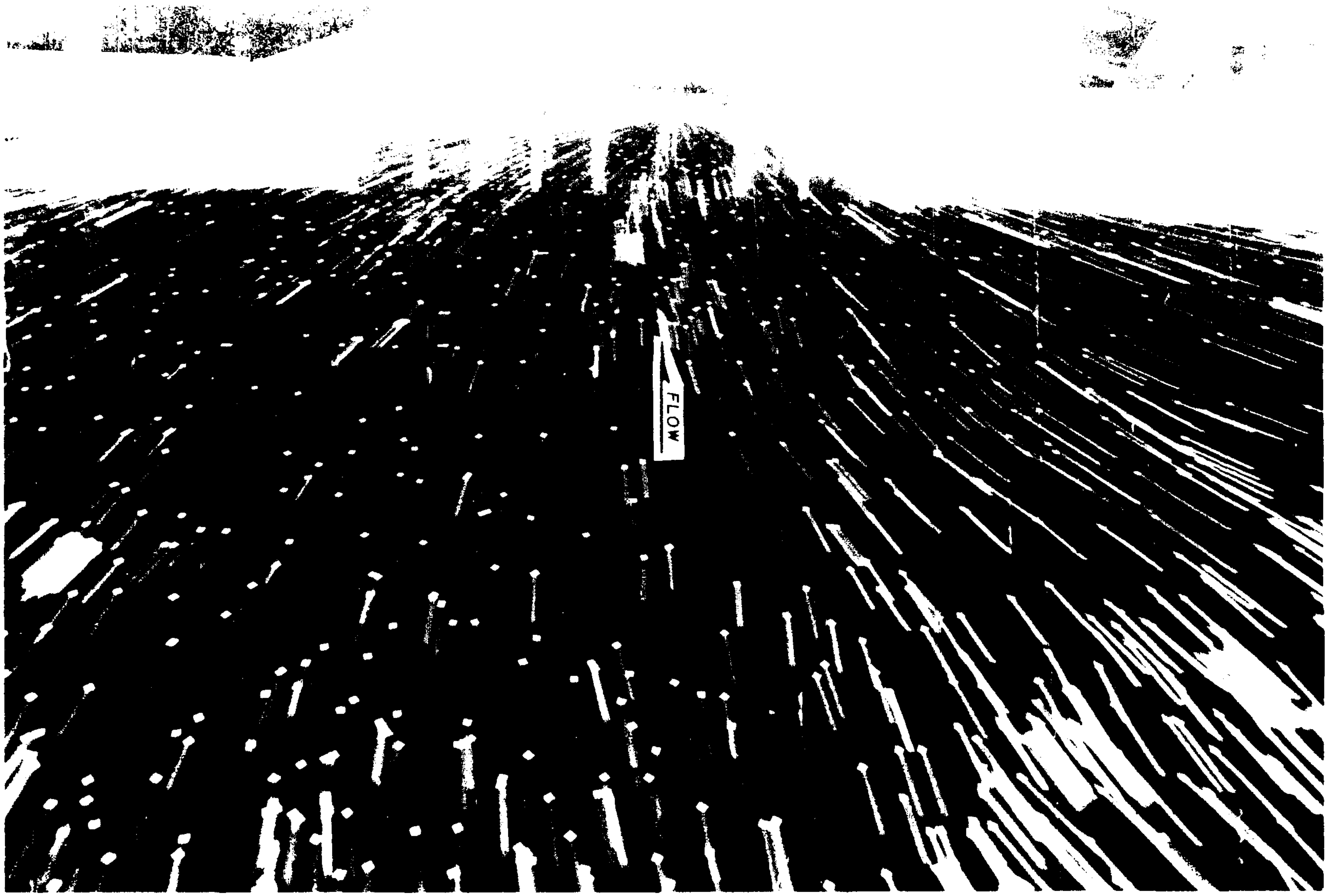


Photo 9. Scheme C gravity control, discharge 4,750 cfs, pool el 426.0, exposure time 25 sec

Photo 10. Surface currents, controlled flow vortices, Scheme C type 1 gravity flow, discharge 9,800 cfs, pool el 426.0, exposure time 10 sec

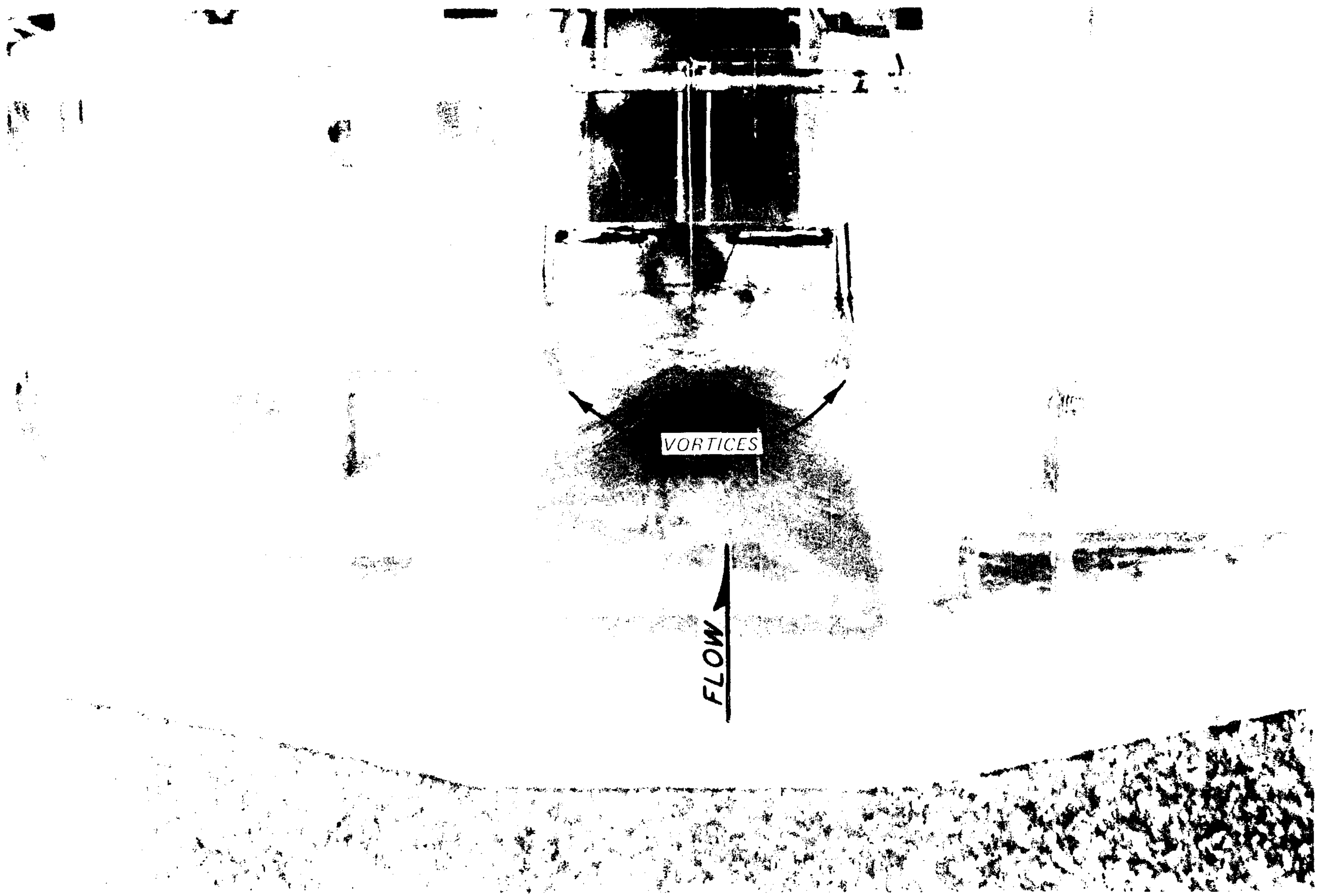


Photo 11. Controlled flow, Scheme C type 4 gravity control, pool el 426.0, gate opening 10 ft

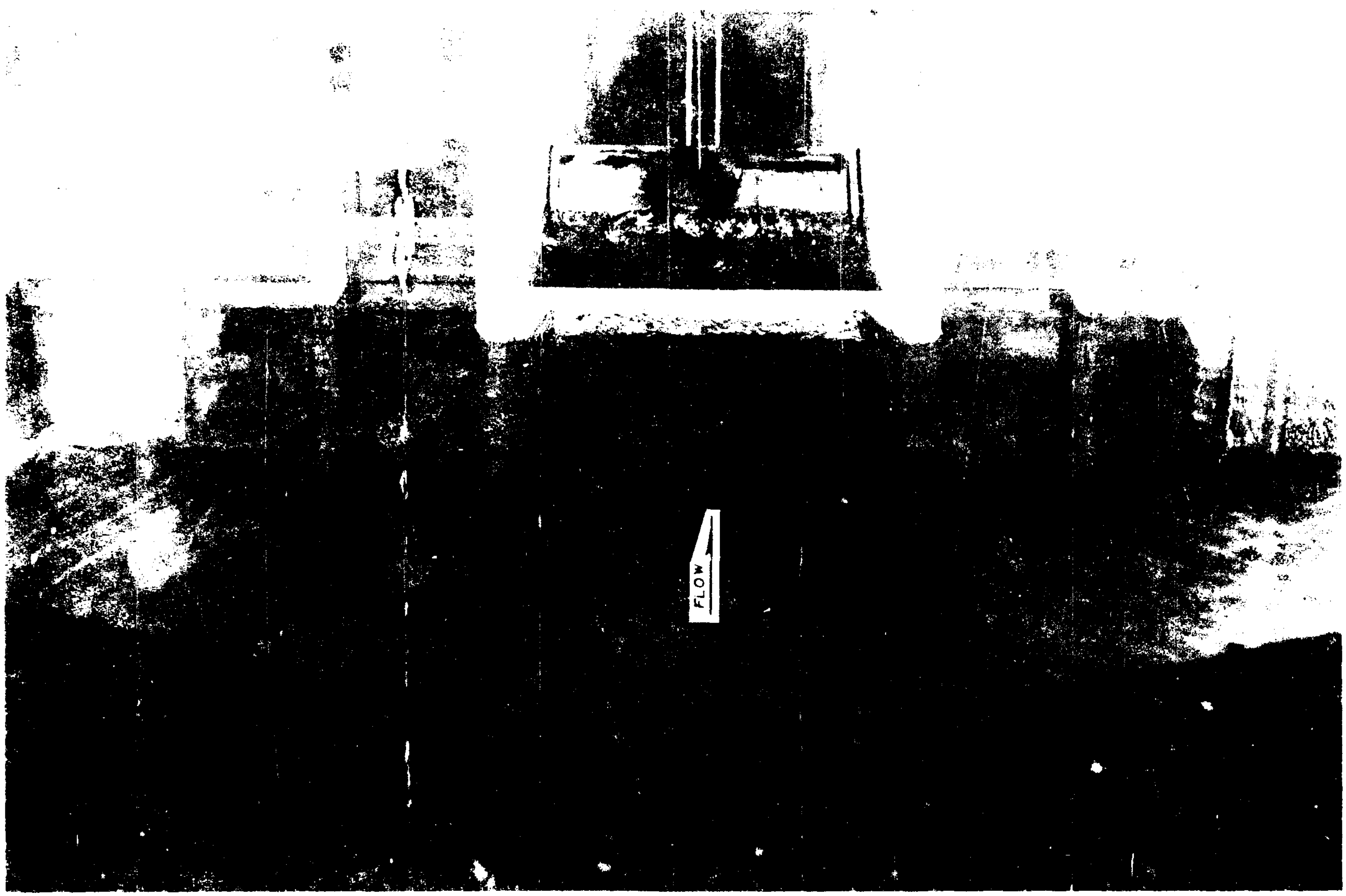


Photo 12. Controlled flow, Scheme C type 5 gravity control without debris, pool el 426.0, gate opening 10 ft

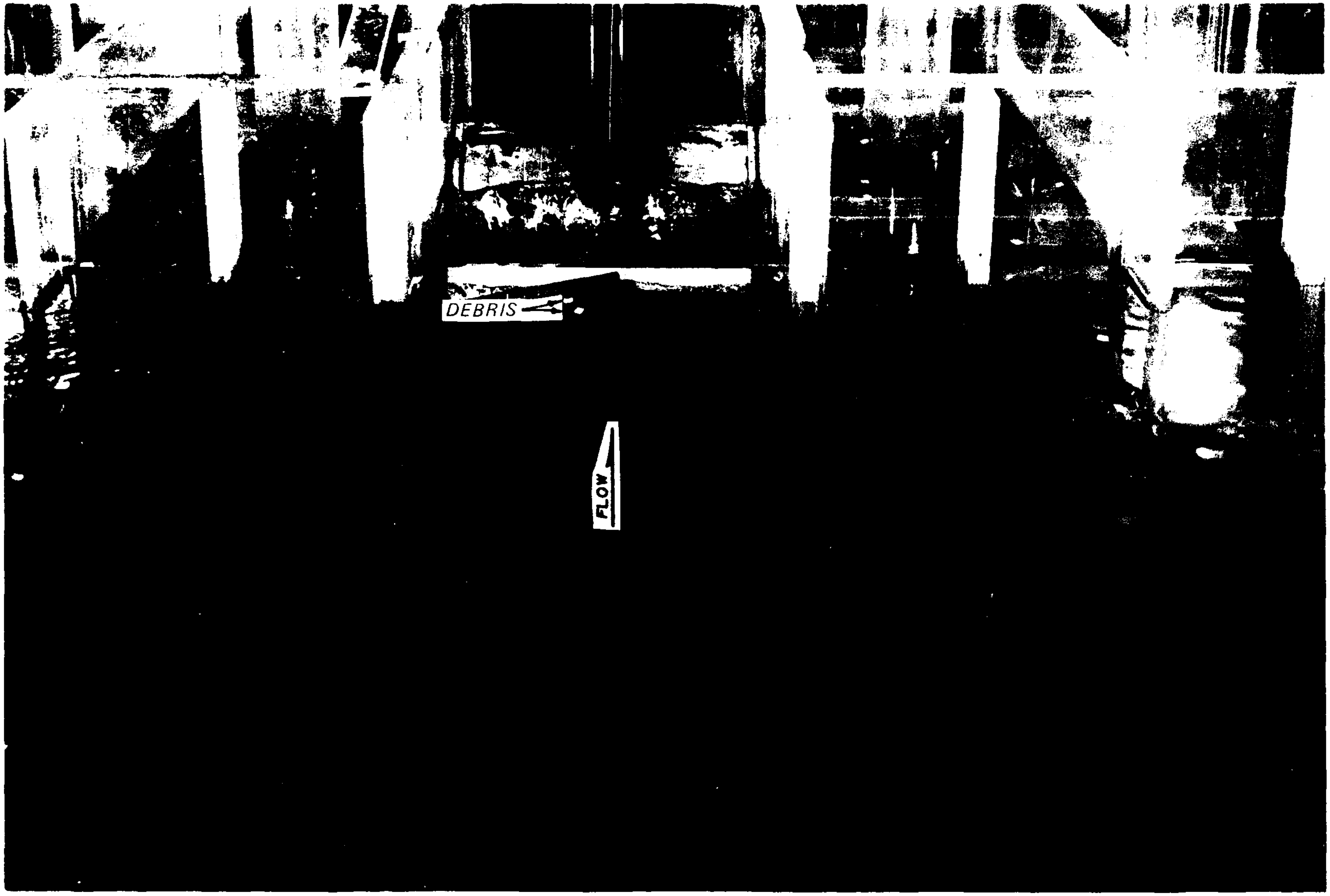


Photo 13. Controlled flow, Scheme C type 5 gravity control with debris, pool el 426.0, gate opening 10 ft

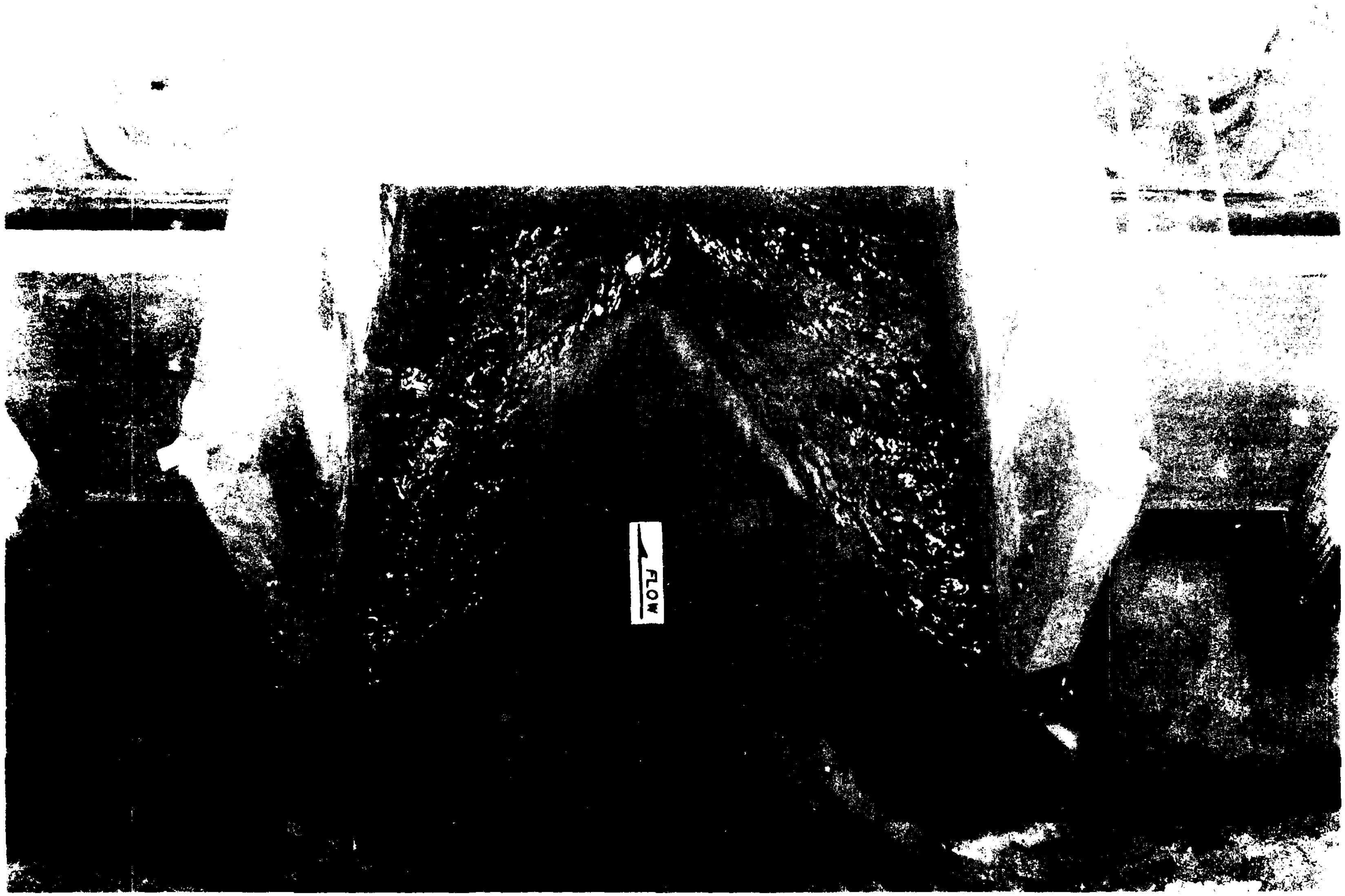
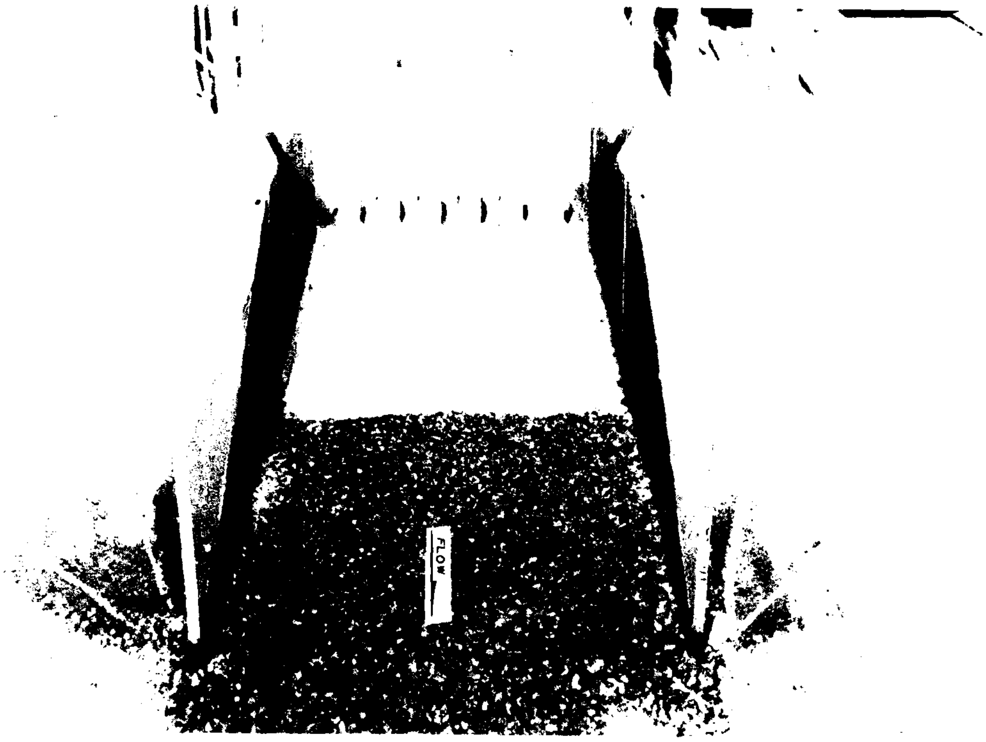


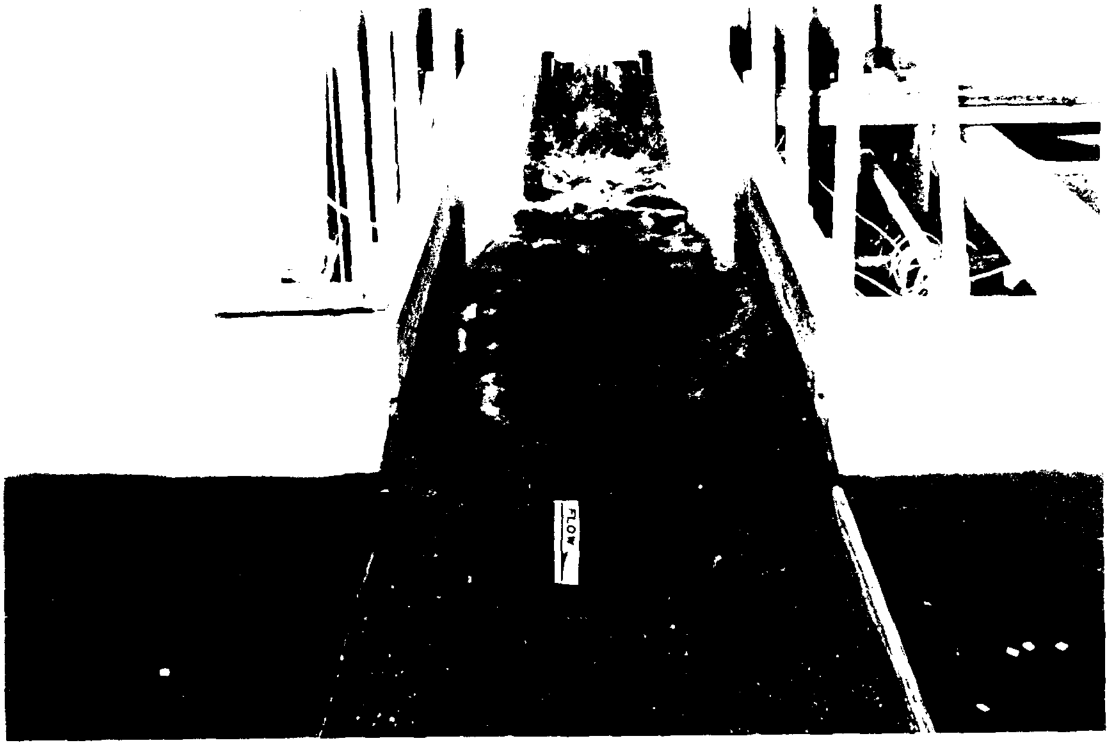
Photo 14. Uncontrolled flow, Scheme C type 5 gravity control with gate full open, pool el 421.3, discharge 17,000 cfs



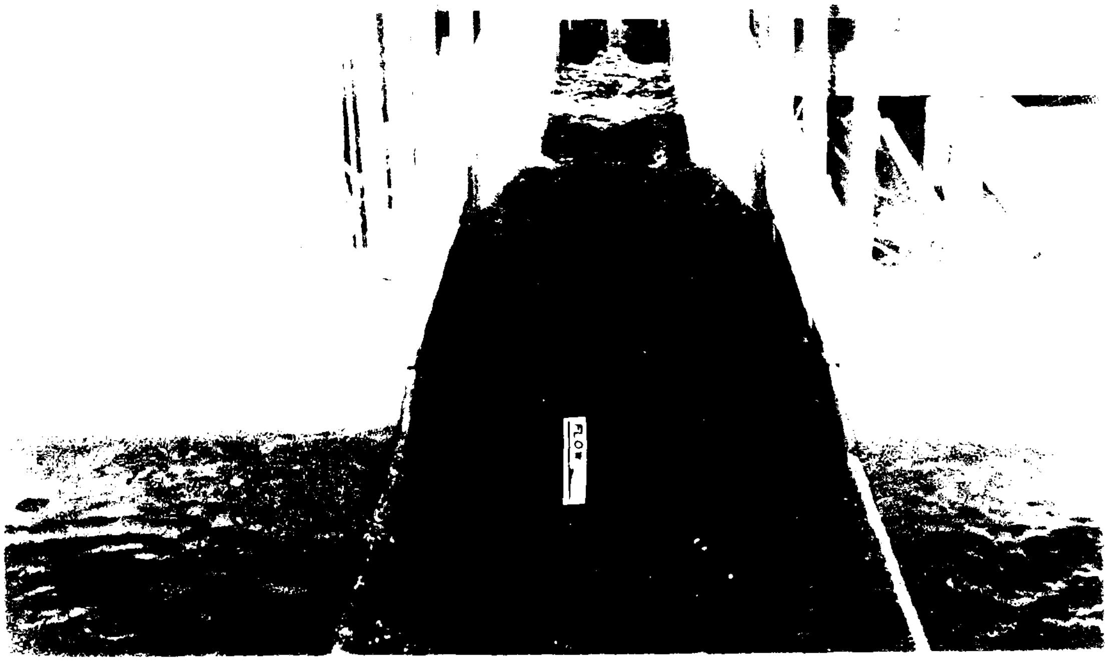
a. Dry bed

b. Discharge 4,750 cfs, gate opening 5 ft, pool el 426.0, tailwater el 401.7

Photo 15. Scheme C type 6 stilling basin (Continued)

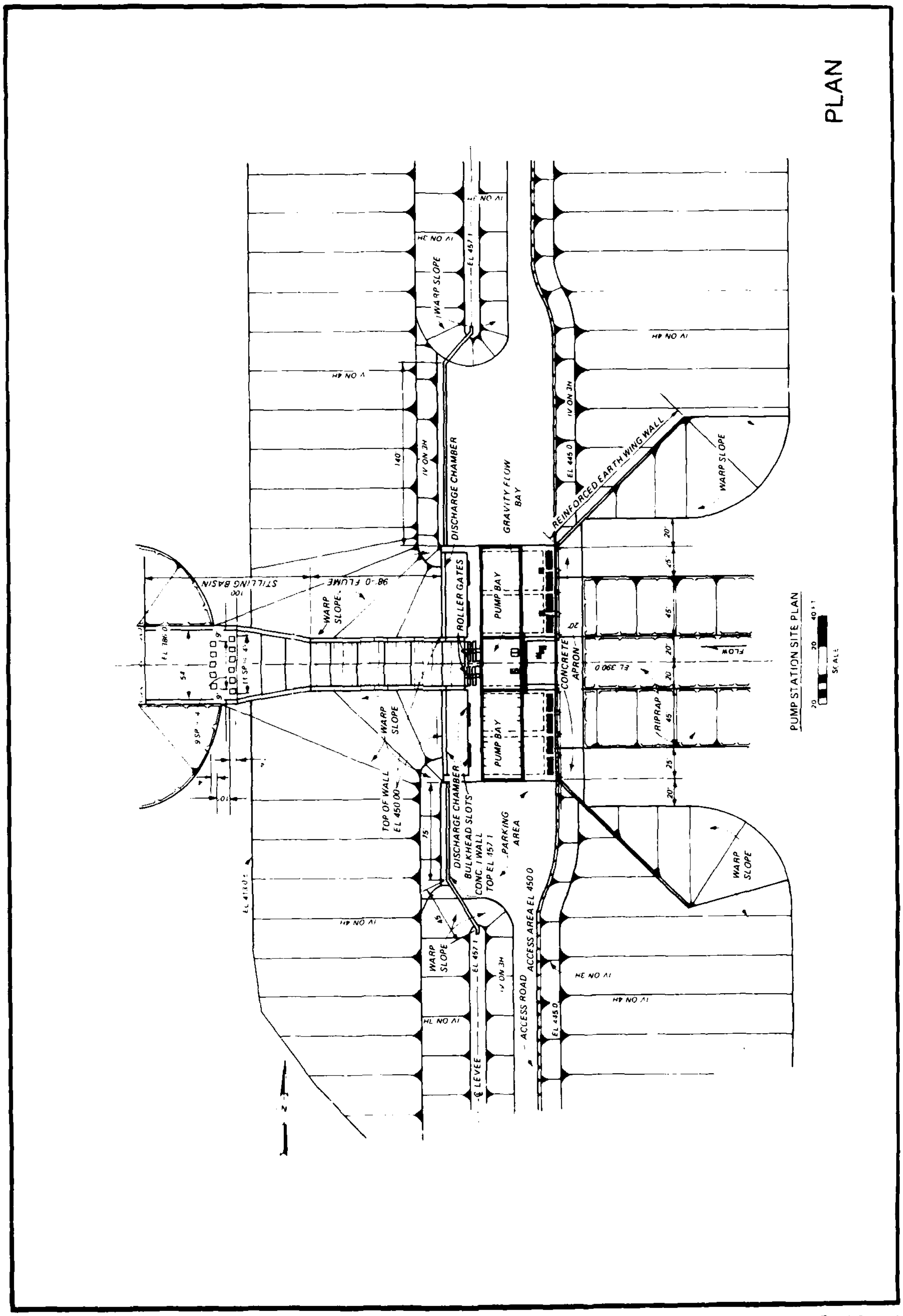


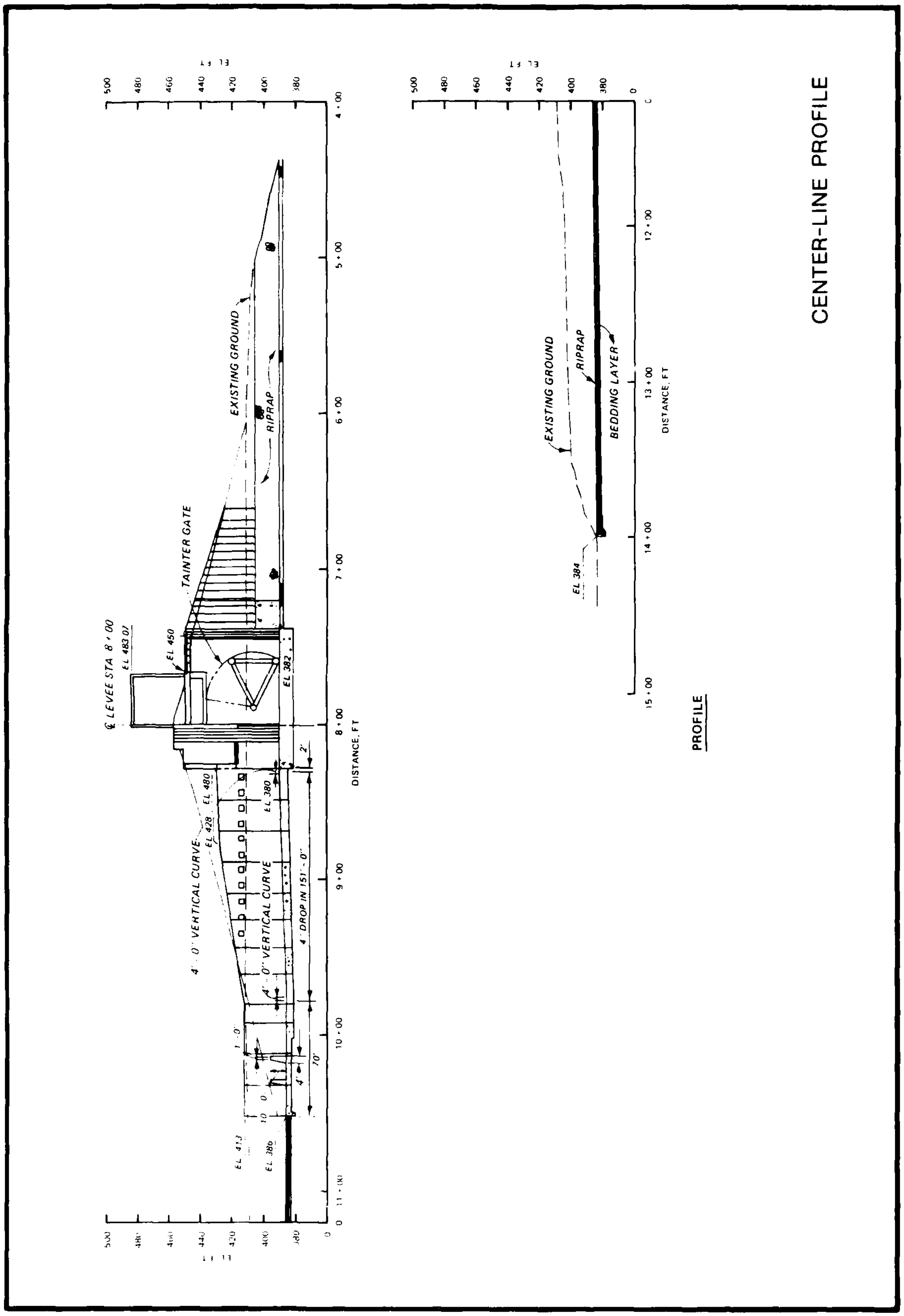
c. Discharge 13,100 cfs, gate opening 15 ft, pool el 426.0, tailwater el 401.7



d. Discharge 17,000 cfs, uncontrolled flow, pool el 421.3, tailwater el 412.5

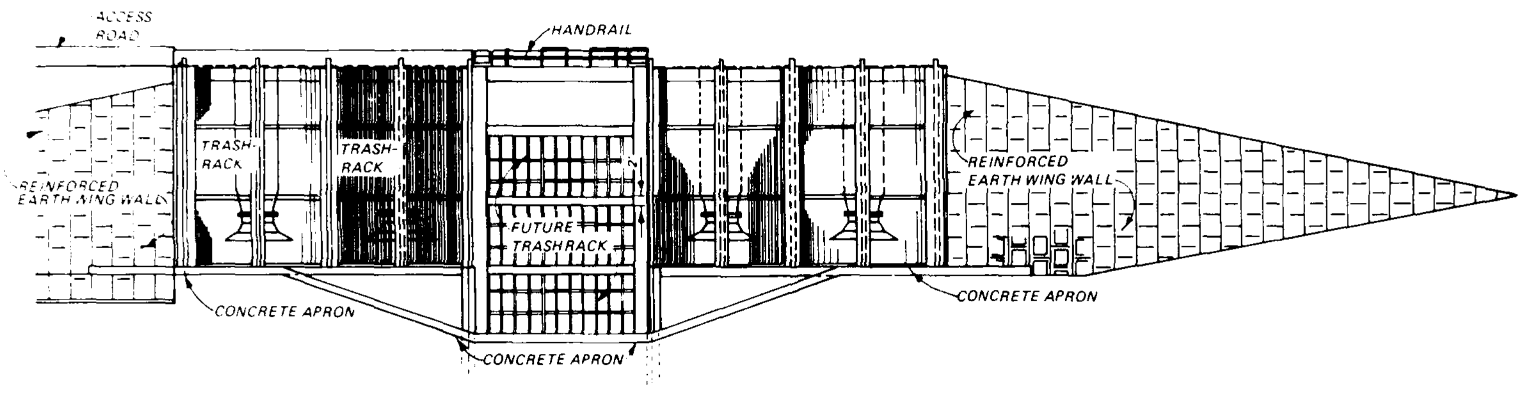
Photo 15. (Concluded)


PLAN
DISCHARGE CHAMBER
GRAVITY FLOW BAY
REINFORCED EARTH WING WALL
WARP SLOPE
STILLING BASIN
98.0 FLUME
ROLLER GATES
PUMP BAY
PUMP BAY
CONCRETE APRON
RIPRAP
FLOW
TOP OF WALL EL 450.00
DISCHARGE CHAMBER
BULKHEAD SLOTS
CONC I WALL TOP EL 457.1
PARKING AREA
ACCESS AREA EL 450.0
ACCESS ROAD
LEVEE
PUMP STATION SITE PLAN
SCALE

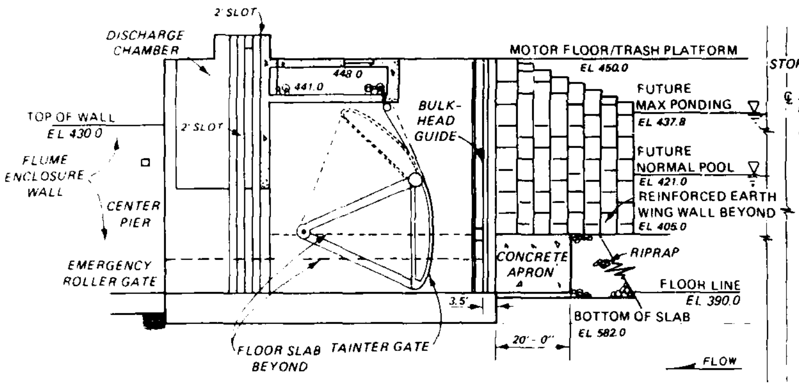


CENTER-LINE PROFILE
EXISTING GROUND
RIPRAP
TAINTER GATE
℄ LEVEE STA 8 + 00
EL 483.07
EL 450
EL 382
EL 480
EL 428
EL 380
4'-0" VERTICAL CURVE
4'-0" VERTICAL CURVE
4' DROP IN 151'-0"
EL 413
EL 386
DISTANCE, FT
EL FT
BEDDING LAYER
EL 384
PROFILE

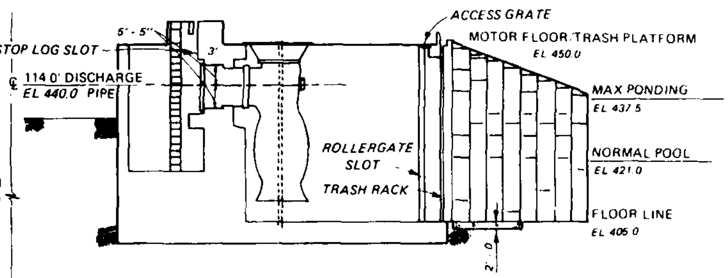
PLATE 2



UPSTREAM ELEVATION

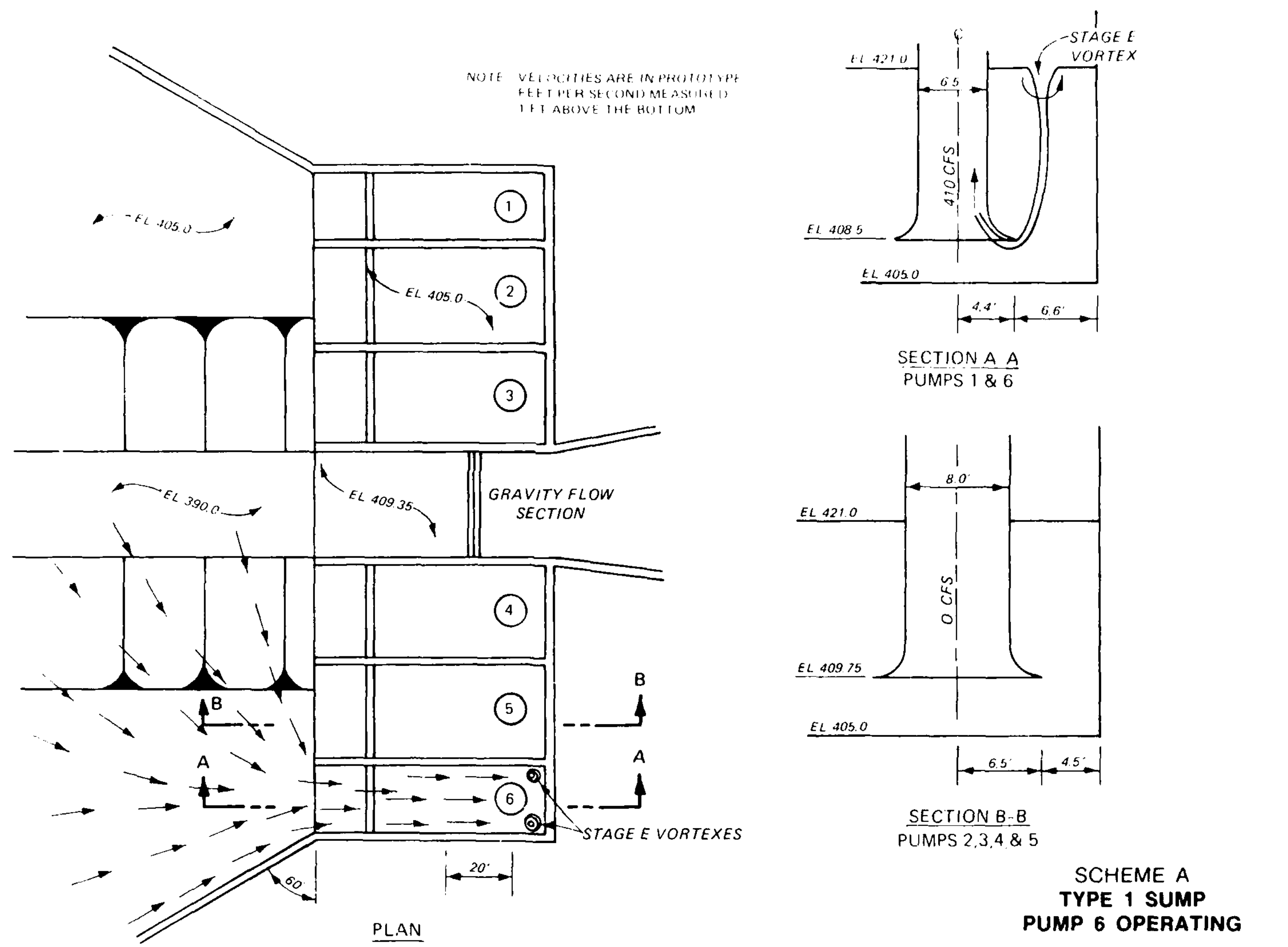


SECTION THRU GRAVITY FLOW BAY

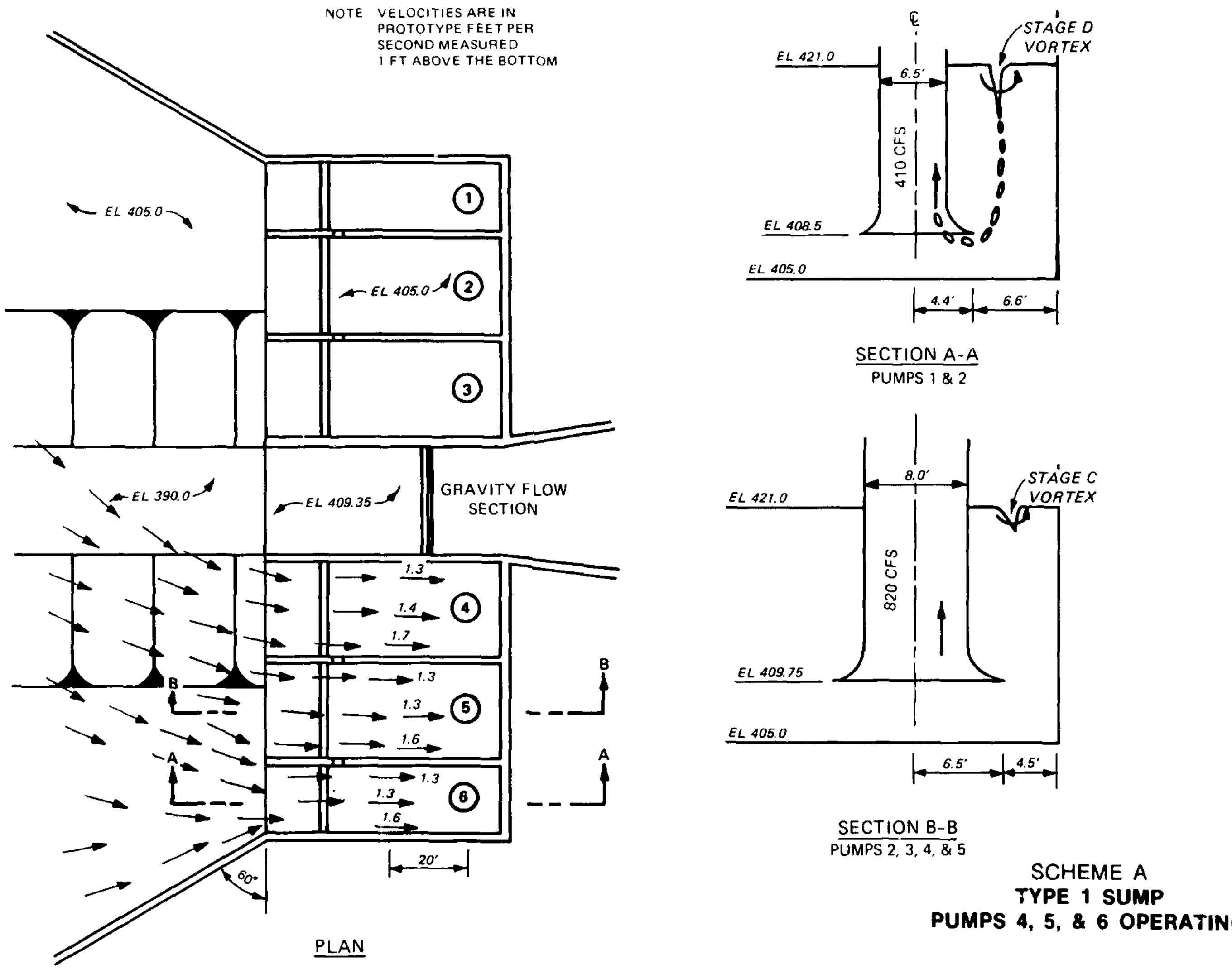


SECTION THRU TYPICAL PUMP BAY

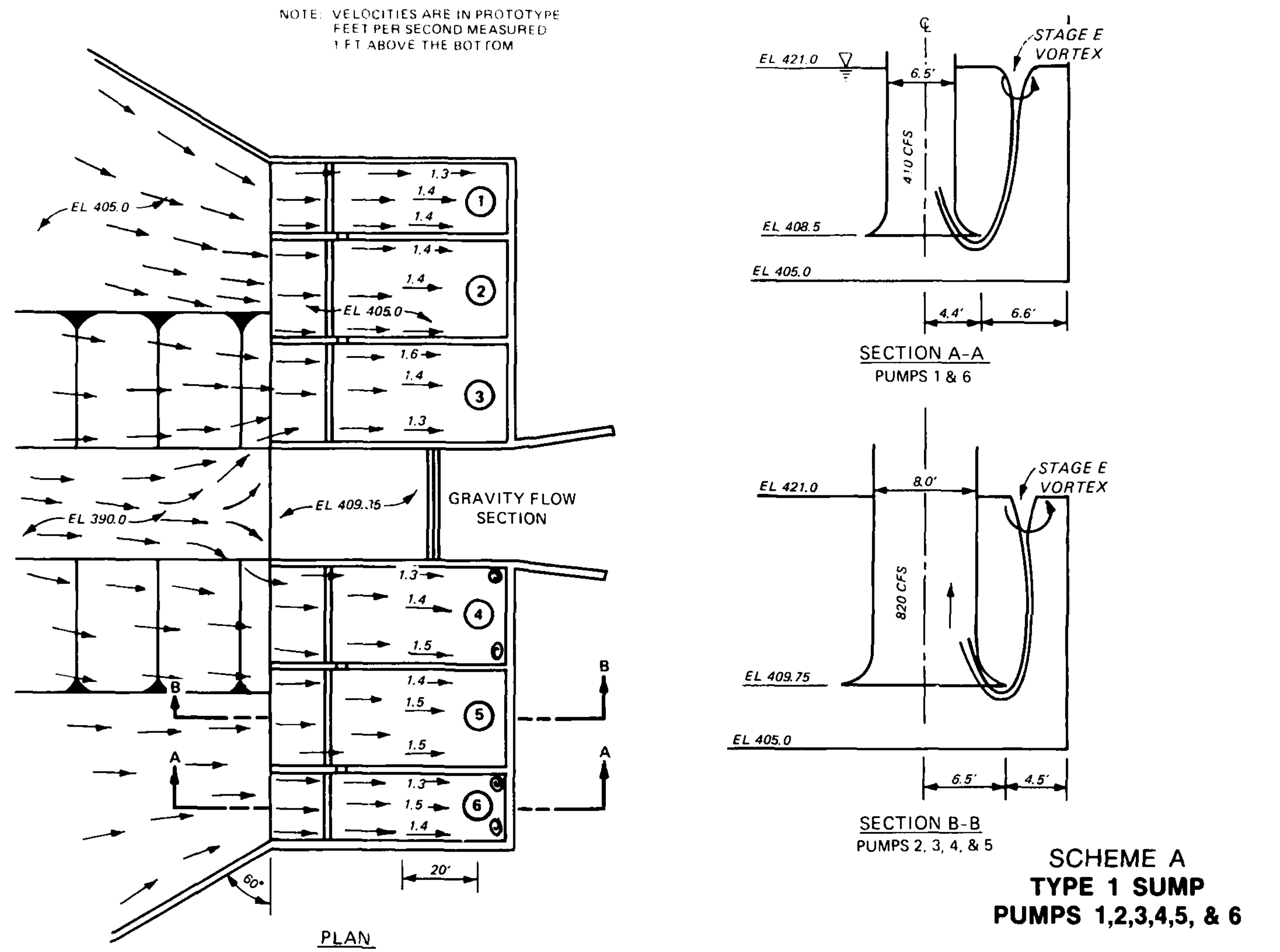
SECTIONS



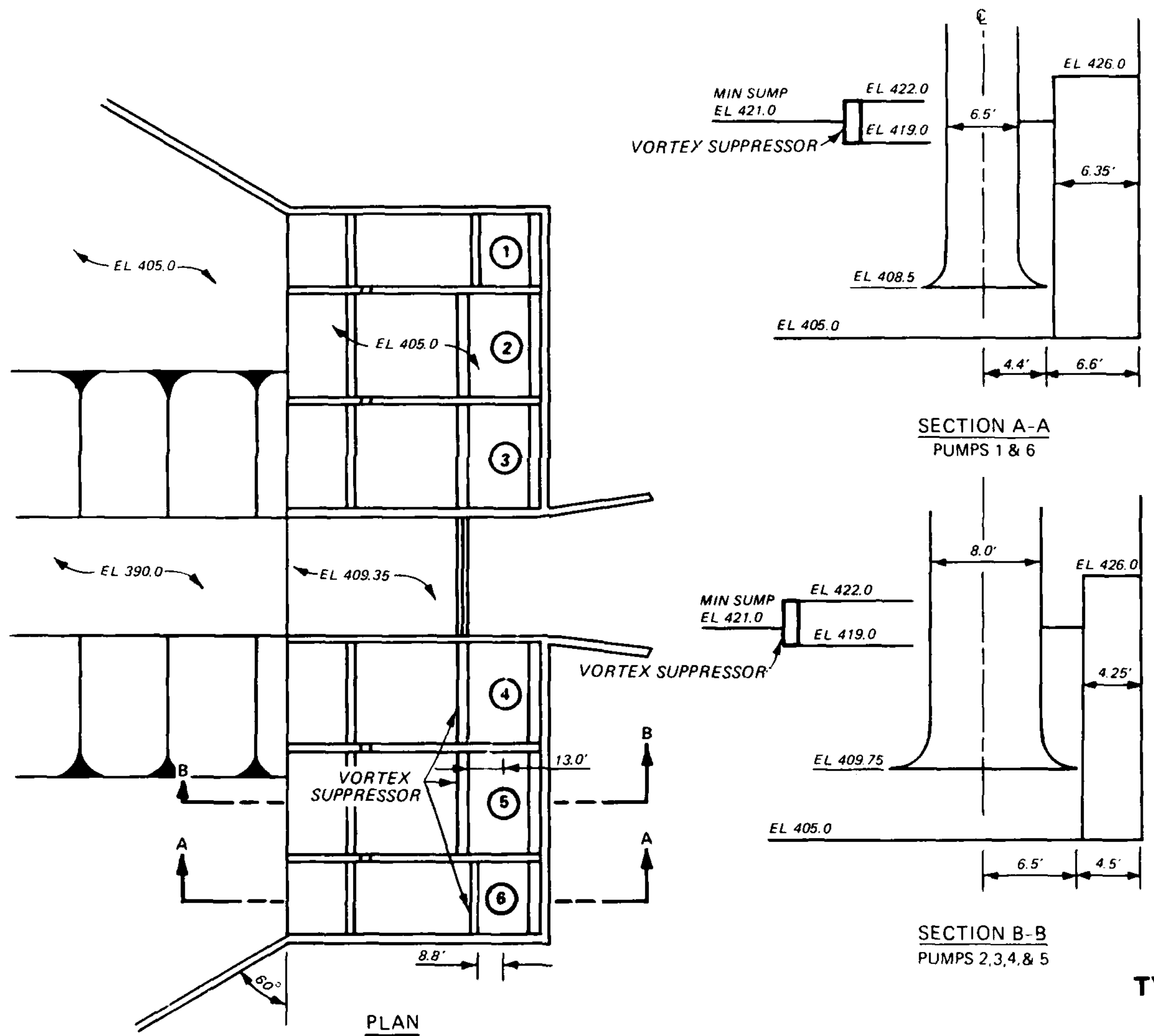
SCHEME A
TYPE 1 SUMP
PUMP 6 OPERATING



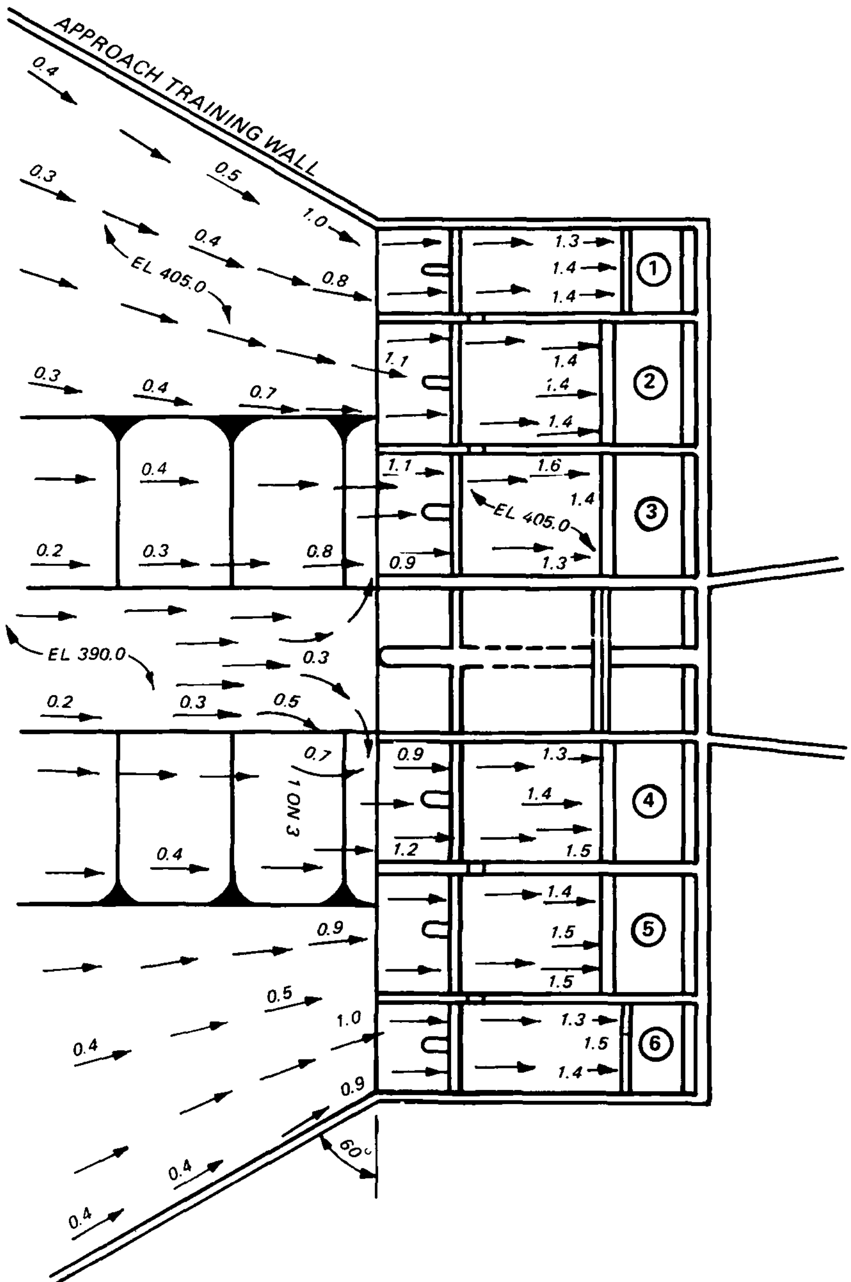
SCHEME A
TYPE 1 SUMP
PUMPS 4, 5, & 6 OPERATING



SCHEME A
TYPE 1 SUMP
PUMPS 1,2,3,4,5, & 6



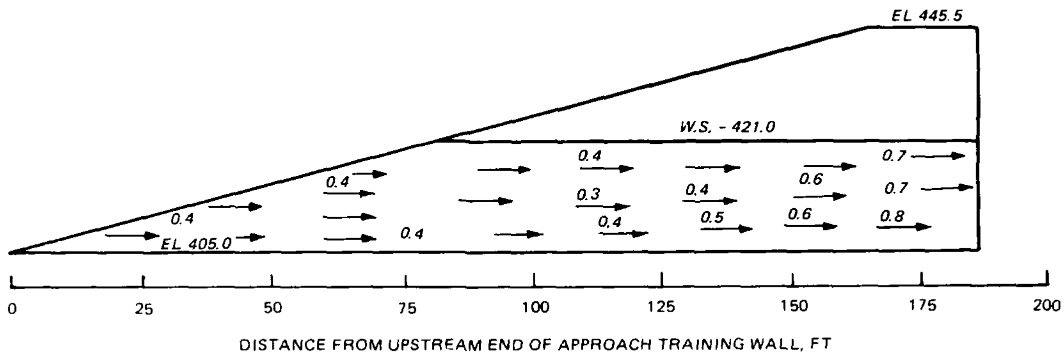
SCHEME A
TYPE 4 SUMP



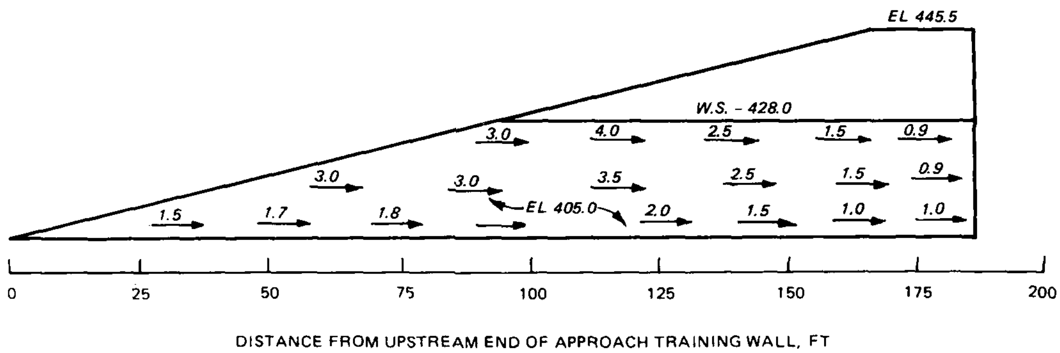
PLAN

NOTE. VELOCITIES ARE IN PROTOTYPE FEET PER SECOND MEASURED 1 FT ABOVE BOTTOM.
PUMPS 1 & 6
Q = 410 CFS PER PUMP
PUMPS 2, 3, 4, & 5
Q = 820 CFS PER PUMP

SCHEME A TYPE 5 DESIGN SUMP
APPROACH VELOCITIES
POOL EL 421.0



a. PUMPED FLOW, ALL PUMPS OPERATING
TOTAL DISCHARGE 4,100 CFS, POOL EL 421.0

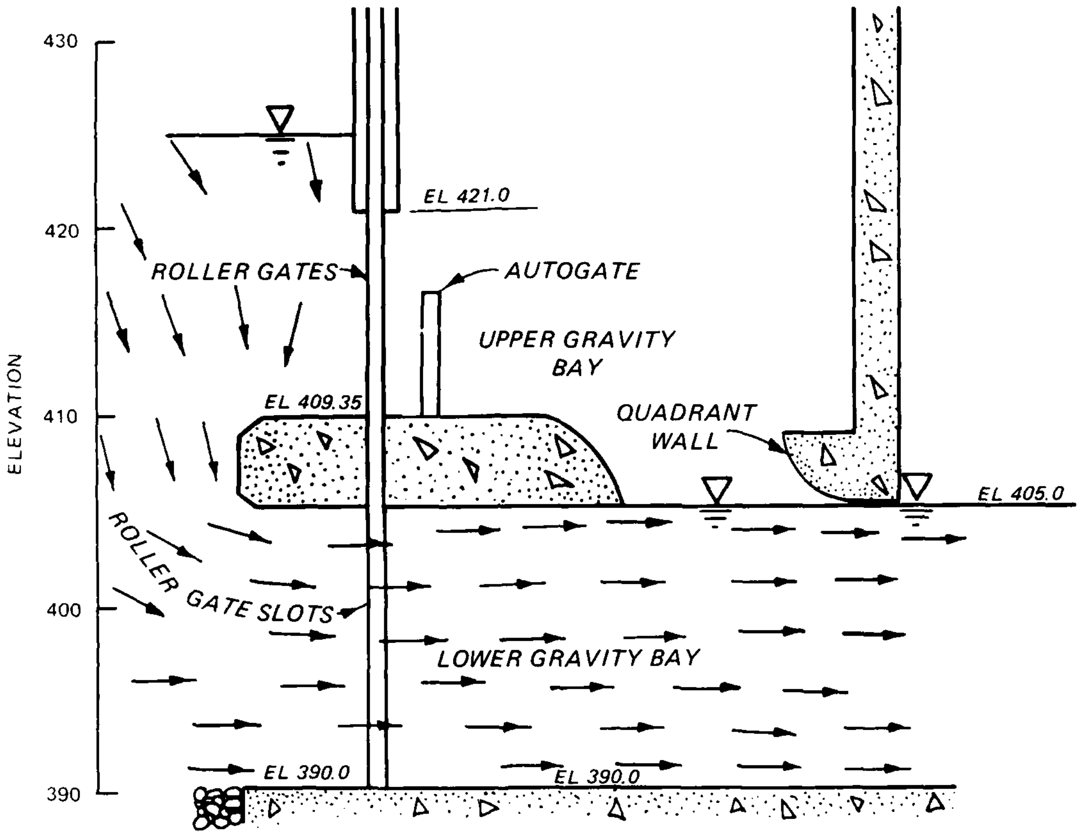


b. GRAVITY FLOW, DISCHARGE 15,000 CFS
POOL EL 428.0, TAILWATER EL 412.5

NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND. CURRENT DISTRIBUTION AND VELOCITIES ALONG THE TWO APPROACH TRAINING WALLS ARE SIMILAR.

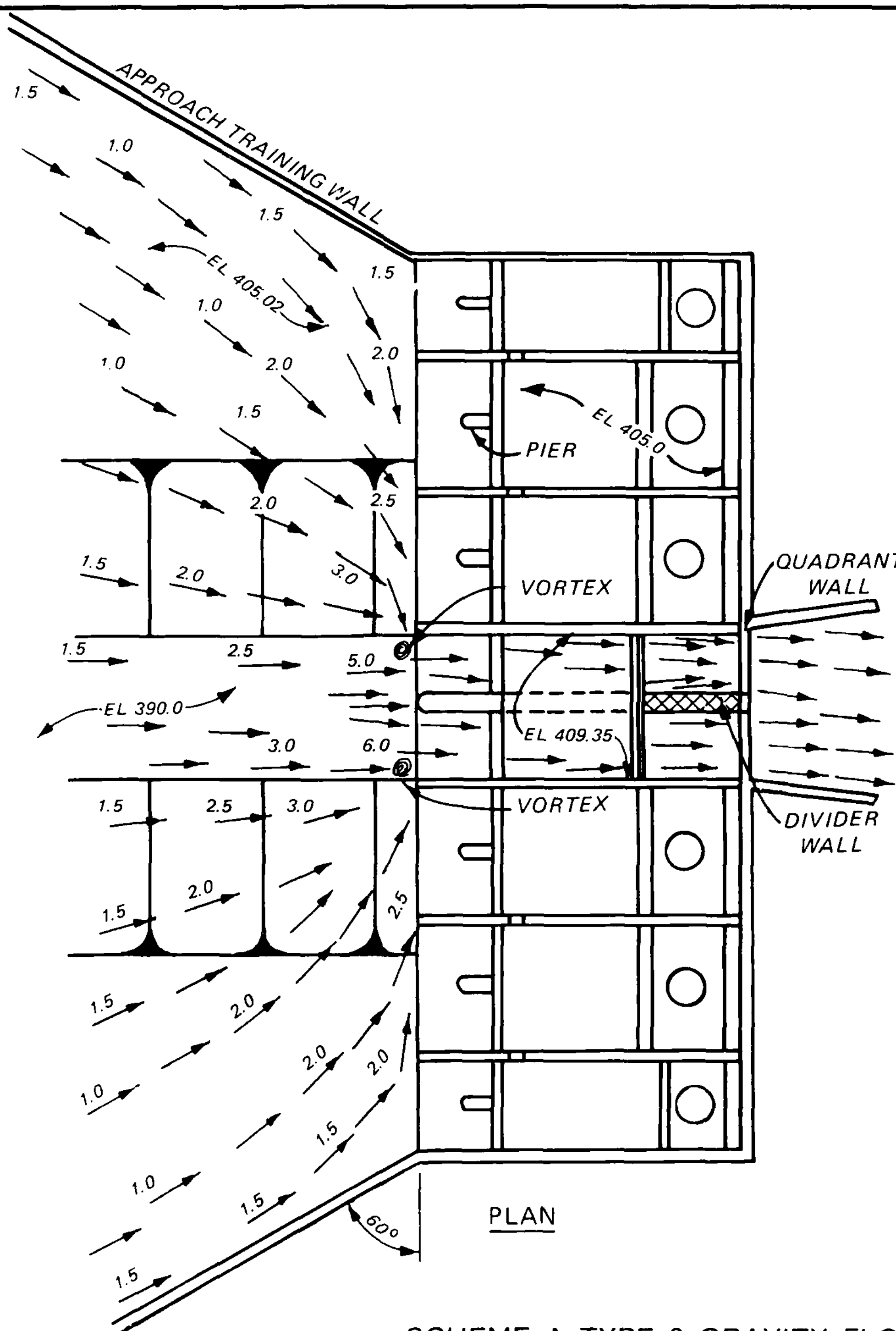
SCHEME A

VELOCITIES ALONG APPROACH TRAINING WALL



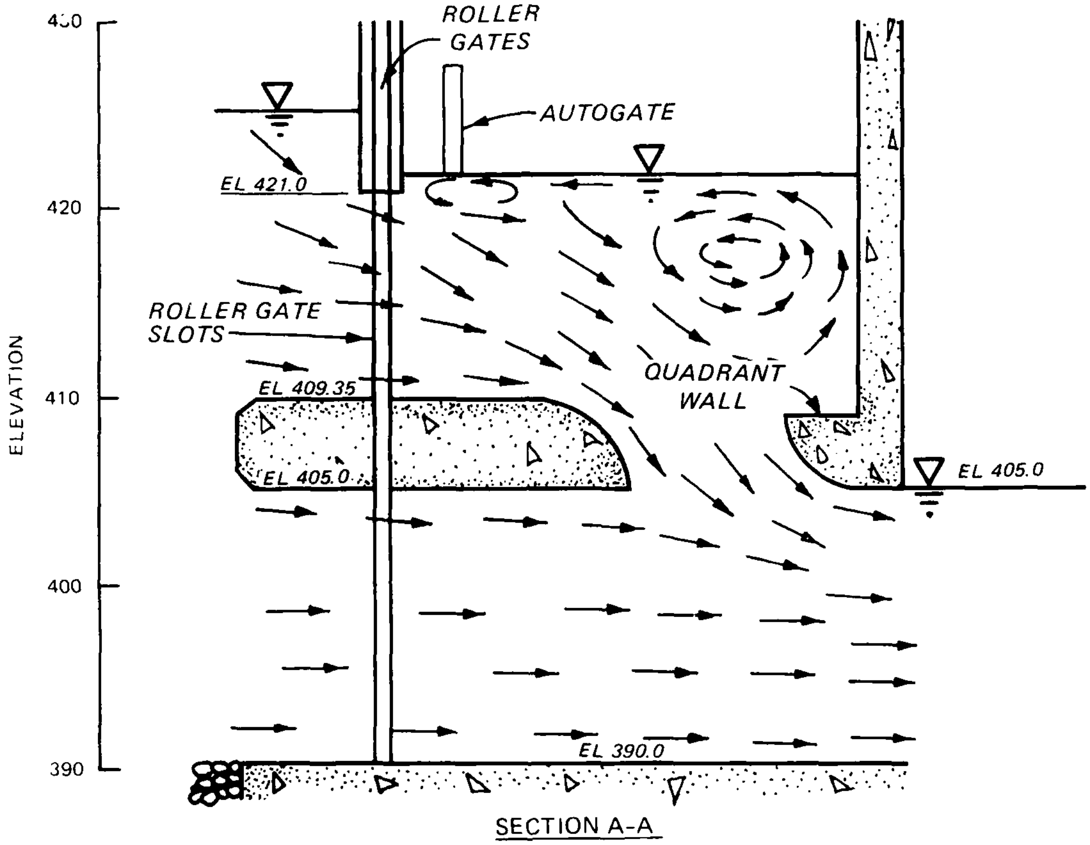
SECTION A-A

SCHEME A TYPE 3 GRAVITY FLOW
TYPICAL FLOW CONDITIONS THROUGH LOWER GRAVITY BAY (NOT TO SCALE)
ROLLER GATES OPEN TO EL 405.0

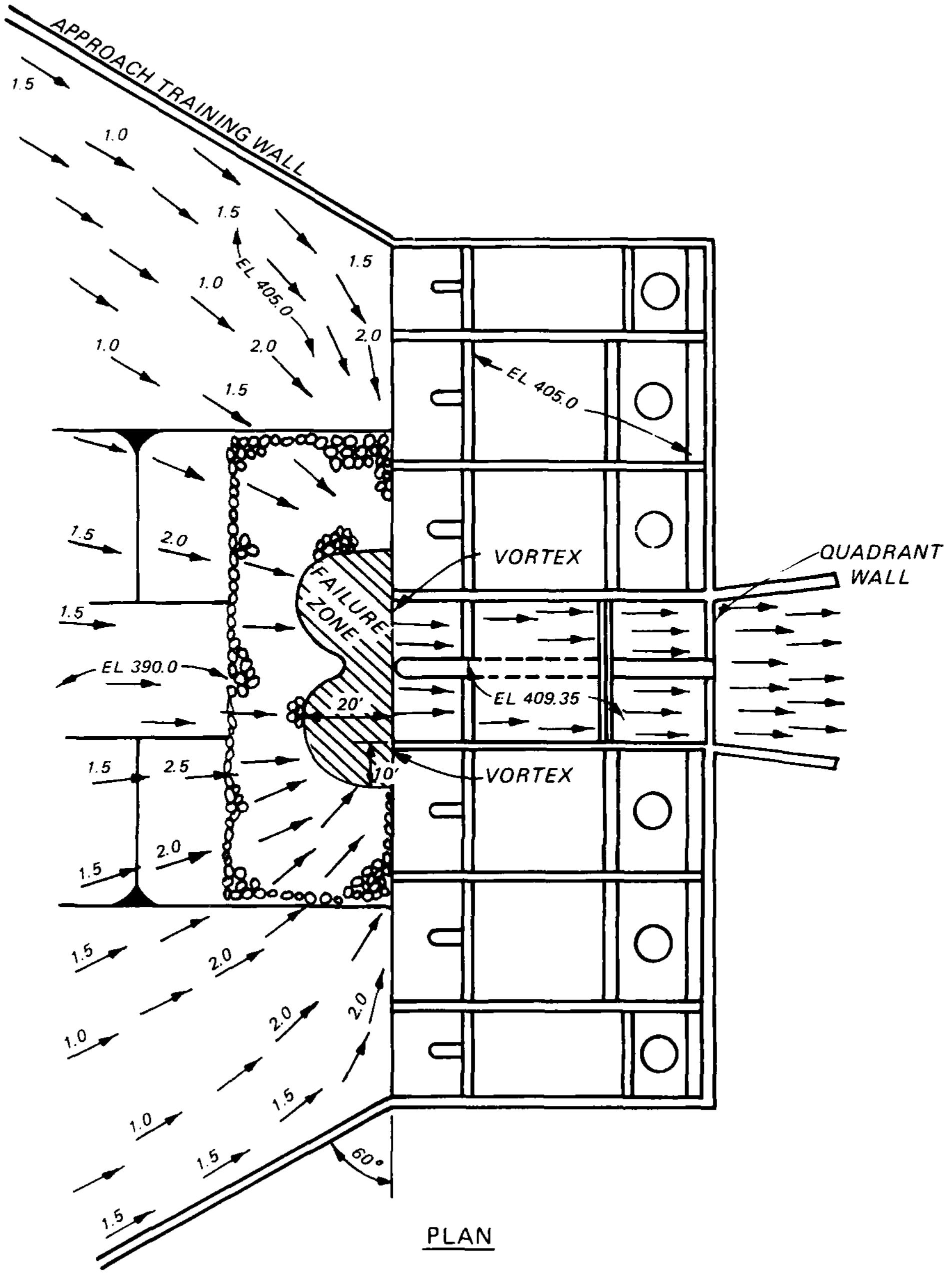


NOTE VELOCITIES ARE IN PROTOTYPE FEET PER SECOND MEASURED 1 FT ABOVE BOTTOM

SCHEME A TYPE 3 GRAVITY FLOW
APPROACH VELOCITIES
DISCHARGE 15,000 CFS
POOL EL 428.0
TAILWATER EL 412.5



SCHEME A TYPE 3 GRAVITY FLOW
TYPICAL FLOW CONDITIONS THROUGH GRAVITY FLOW SECTION (NOT TO SCALE)
ROLLER GATES OPEN TO EL 421.0

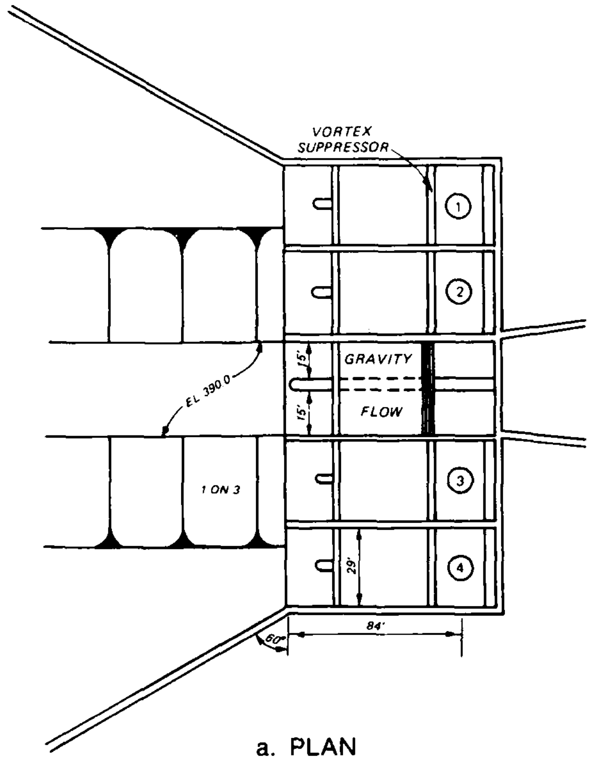


PLAN

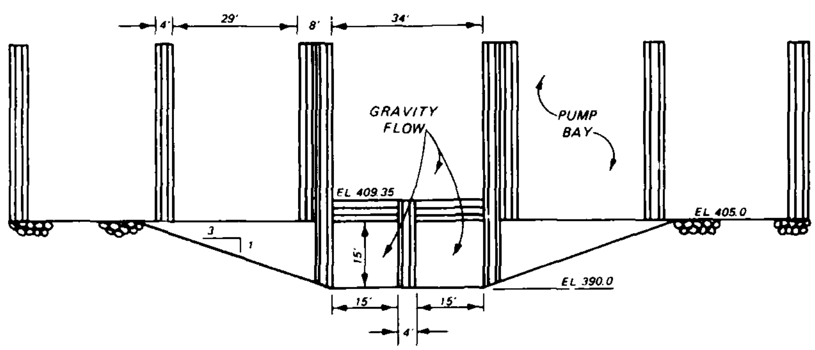
NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND MEASURED 1 FOOT ABOVE BOTTOM

FAILURE ZONE DEVELOPED DURING 2 HOURS (PROTOTYPE) OPERATION

SCHEME A TYPE 3 GRAVITY FLOW
RIPRAP INVESTIGATION
RIPRAP 12 IN. THICK
d_{50} = 6 IN.
DISCHARGE 15,000 CFS
POOL EL 428.0
TAILWATER EL 412.5

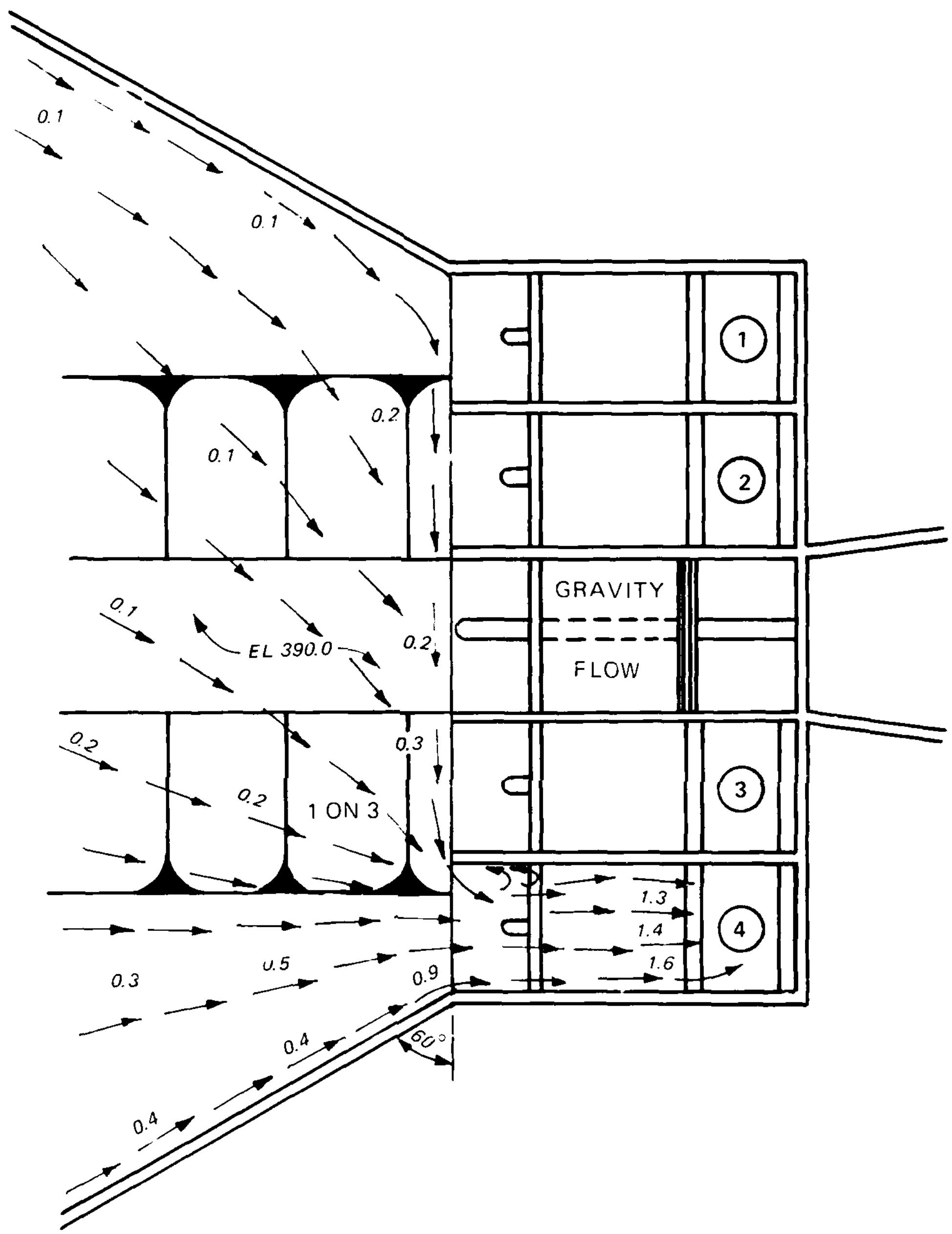


a. PLAN



b. UPSTREAM ELEVATION

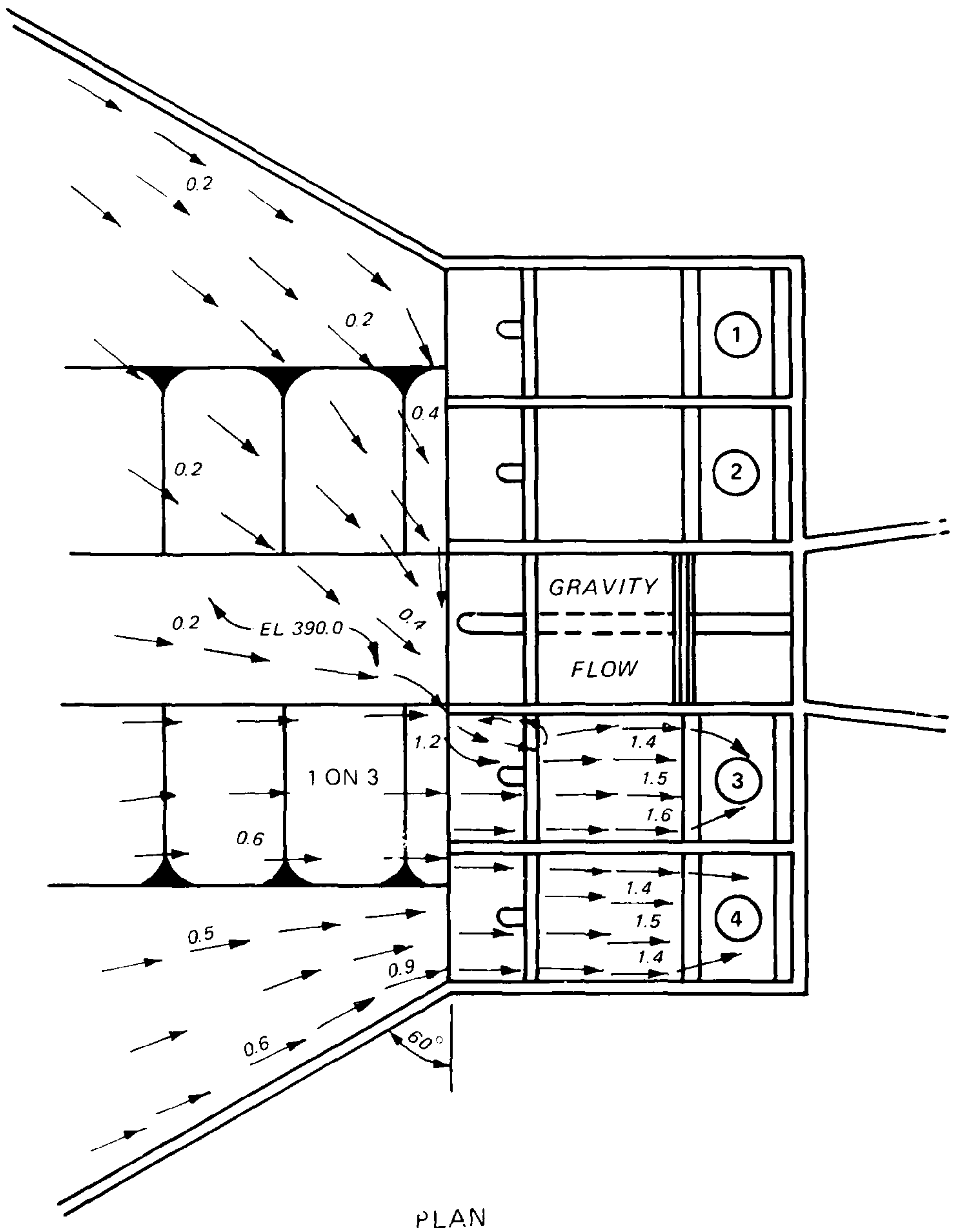
SCHEME B



PLAN

NOTE. VELOCITIES ARE IN PROTOTYPE FEET PER SECOND MEASURED 1 FT ABOVE BOTTOM. Q = 1 025 CFS PER PUMP WATER-SURFACE EL 421

SCHEME B TYPE 1 SUMP
MAGNITUDE AND DIRECTION OF CURRENTS DURING PUMPING
PUMP OPERATING: 4

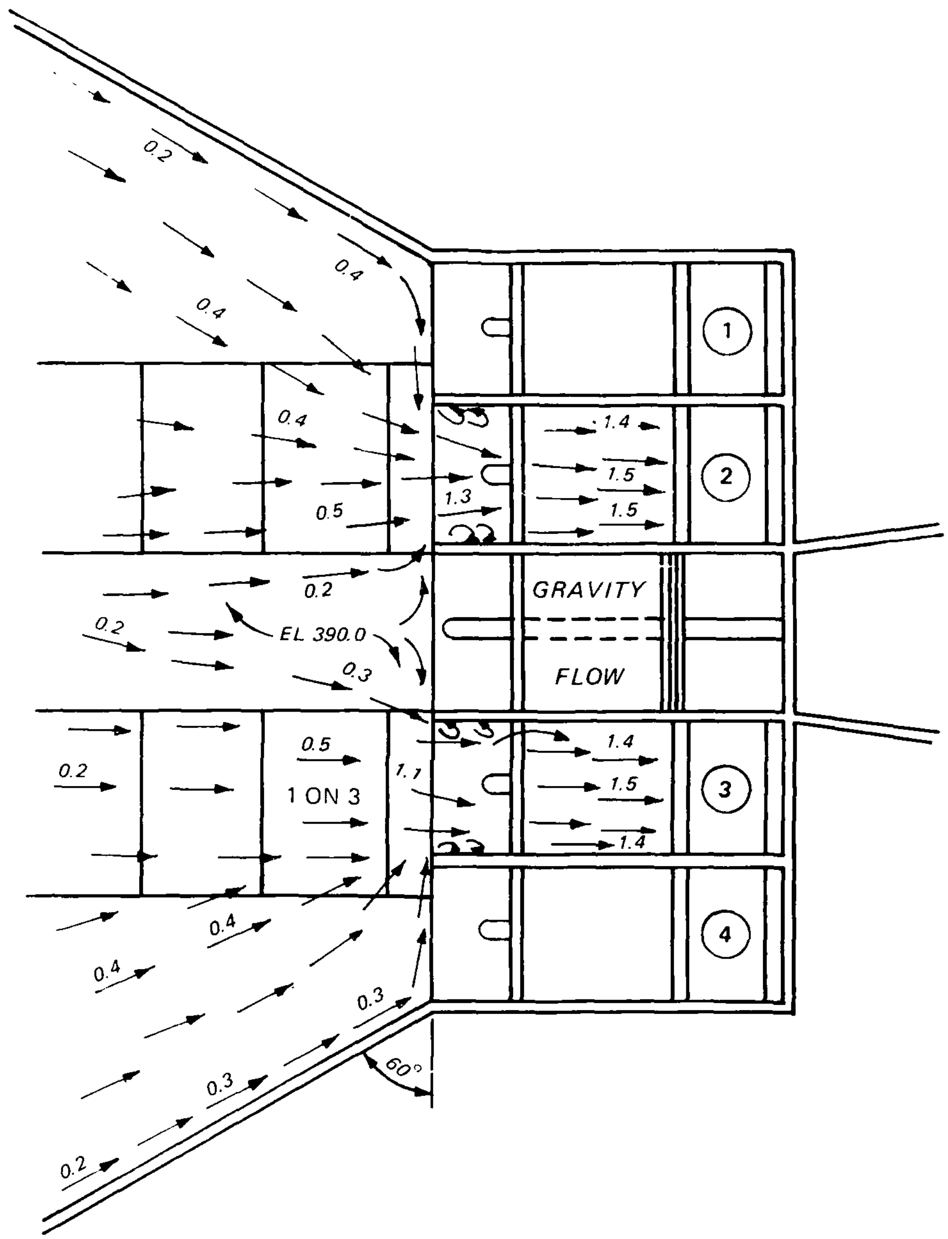


PLAN

NOTE VELOCITIES ARE IN PROTOTYPE FEET PER SECOND MEASURED 1 FT ABOVE BOTTOM.
Q = 1,025 CFS PER PUMP
WATER-SURFACE EL 421

SCHEME B TYPE 1 SUMP

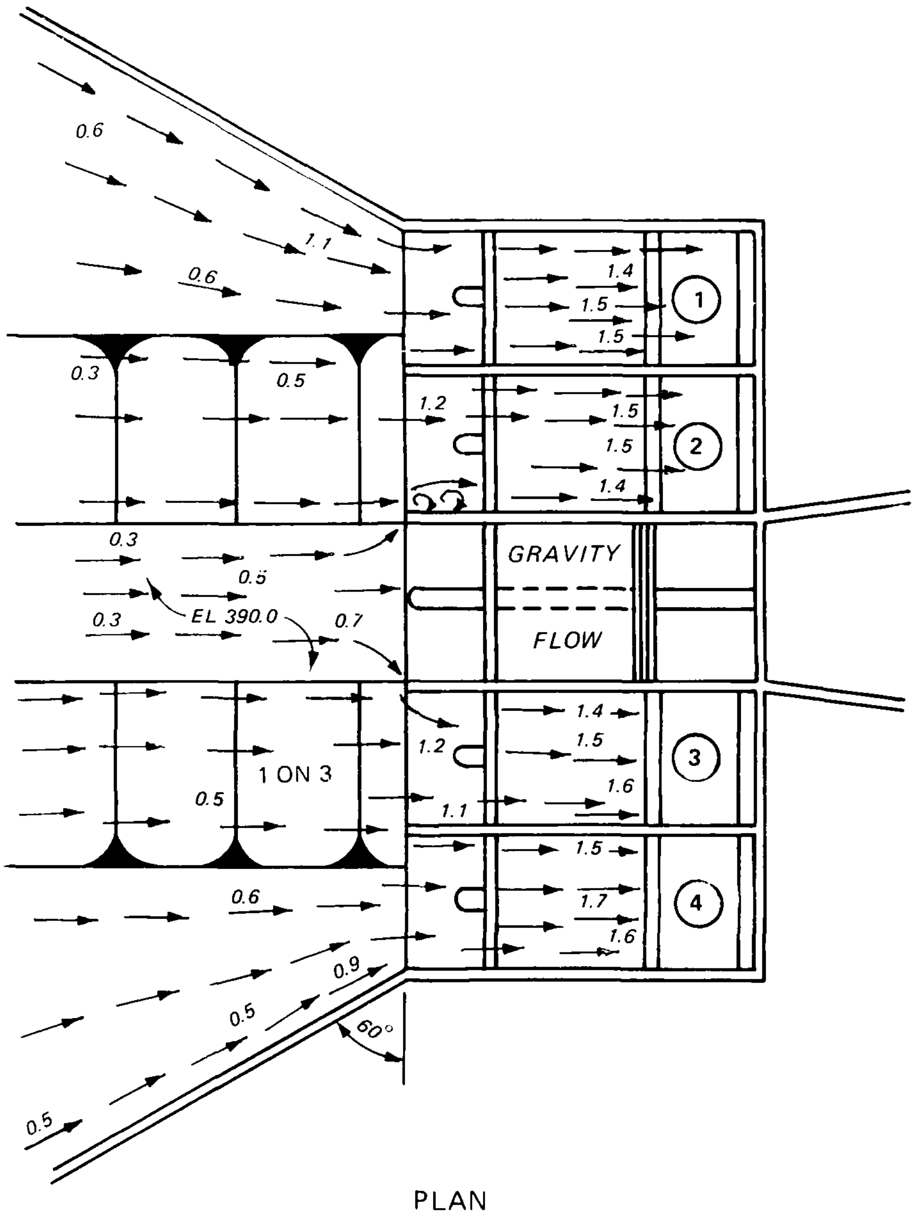
MAGNITUDE AND DIRECTION OF CURRENTS DURING PUMPING PUMPS OPERATING: 3 & 4



PLAN

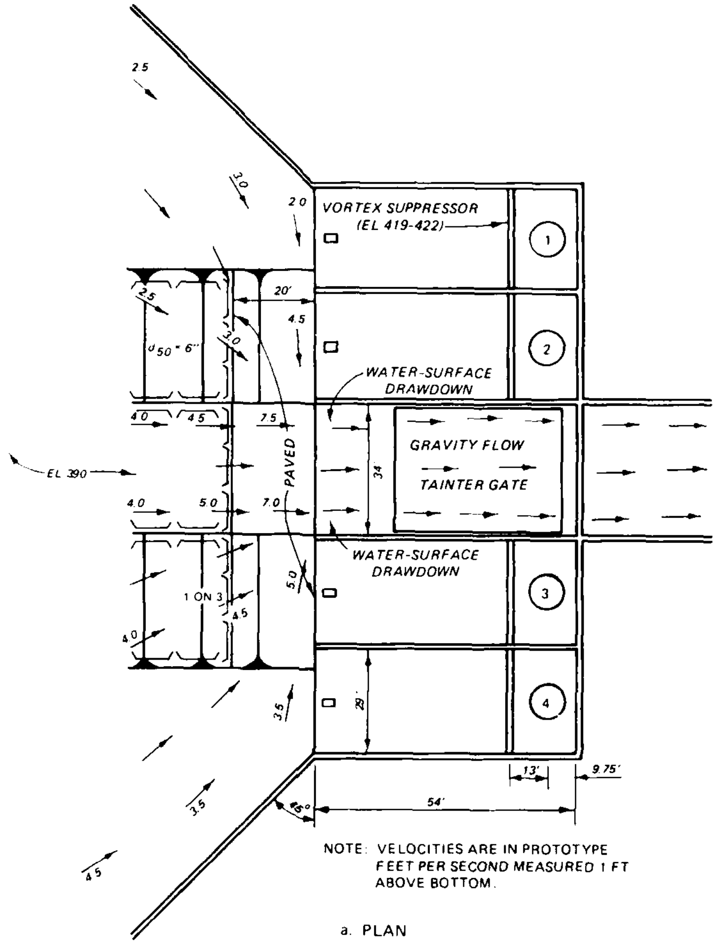
NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND MEASURED 1 FT ABOVE BOTTOM
Q = 1,025 CFS PER PUMP
WATER-SURFACE EL 421

SCHEME B TYPE 1 SUMP
MAGNITUDE AND DIRECTION OF CURRENTS DURING PUMPING PUMPS OPERATING: 2 & 3

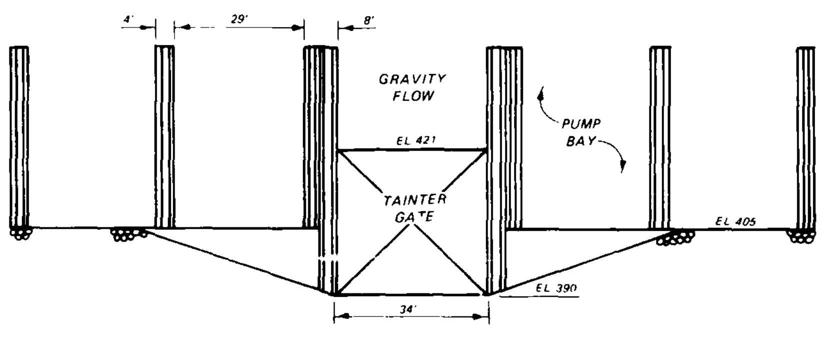


NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND MEASURED 1 FT ABOVE BOTTOM
Q = 1,025 CFS PER PUMP
WATER-SURFACE EL 421

SCHEME B TYPE 1 SUMP
MAGNITUDE AND DIRECTION OF CURRENTS DURING PUMPING PUMPS OPERATING: 1, 2, 3, & 4



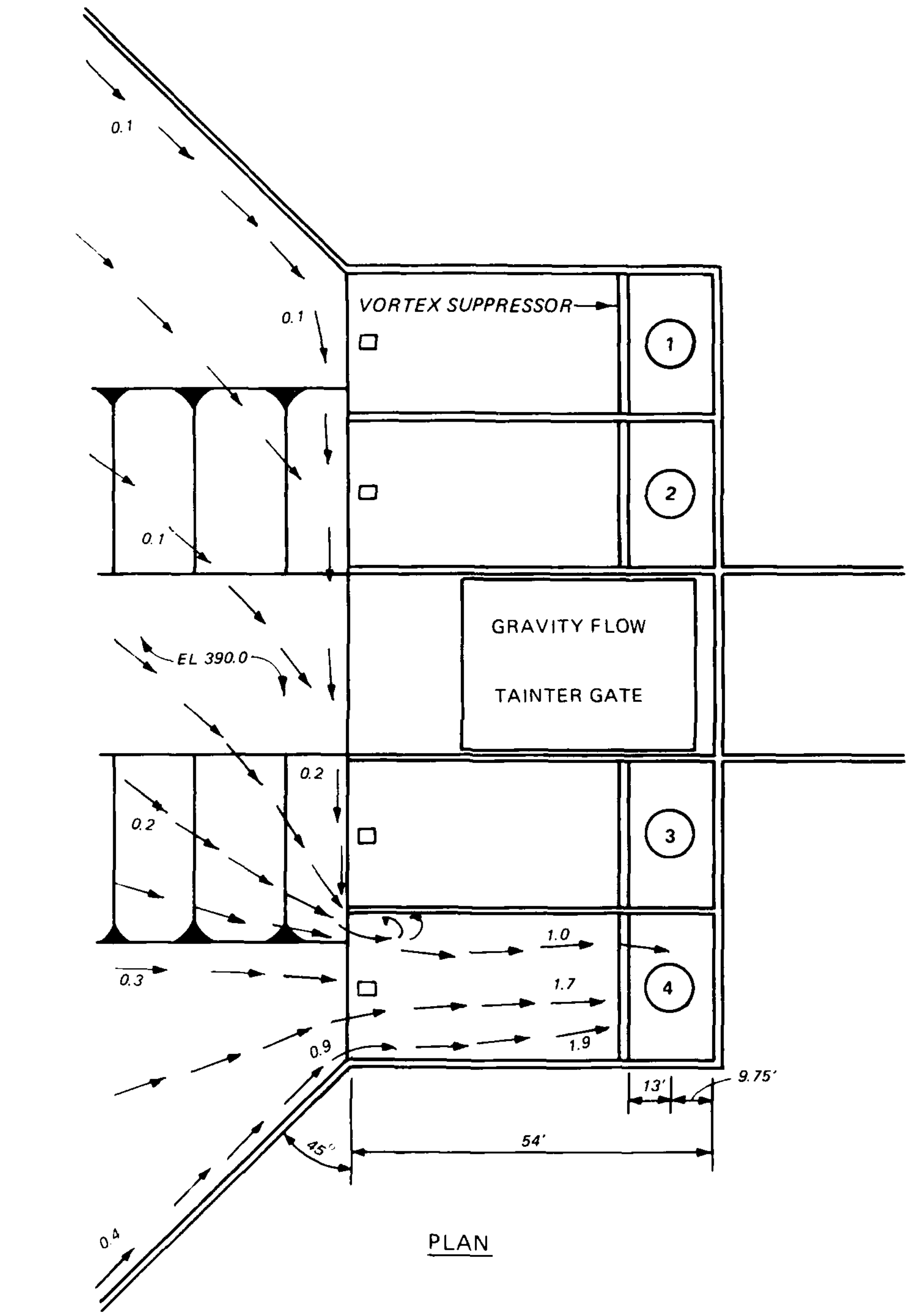
a. PLAN



b. UPSTREAM ELEVATION

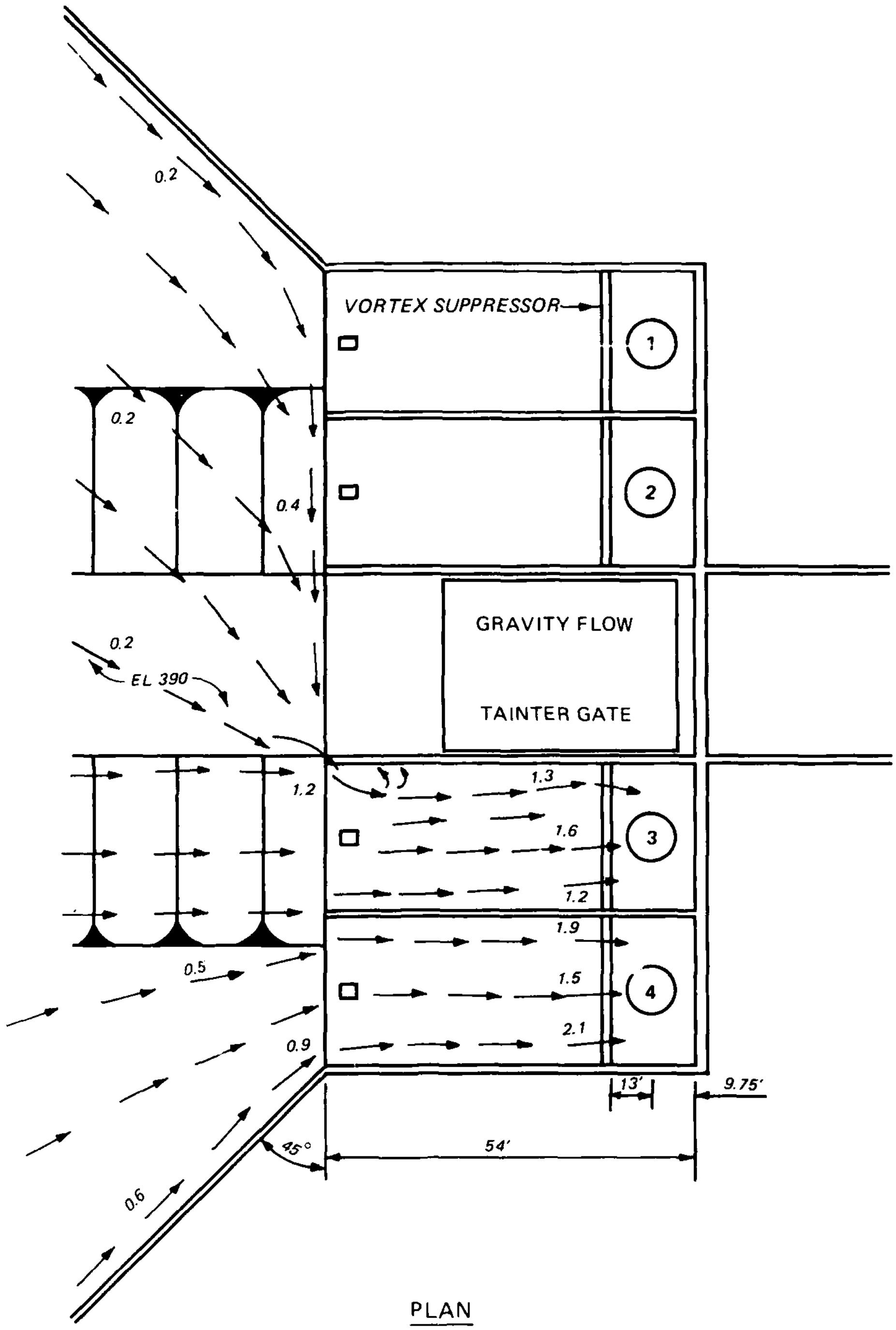
SCHEME C

DISCHARGE 17,000 CFS
POOL EL 421.3
TAILWATER EL 412.5



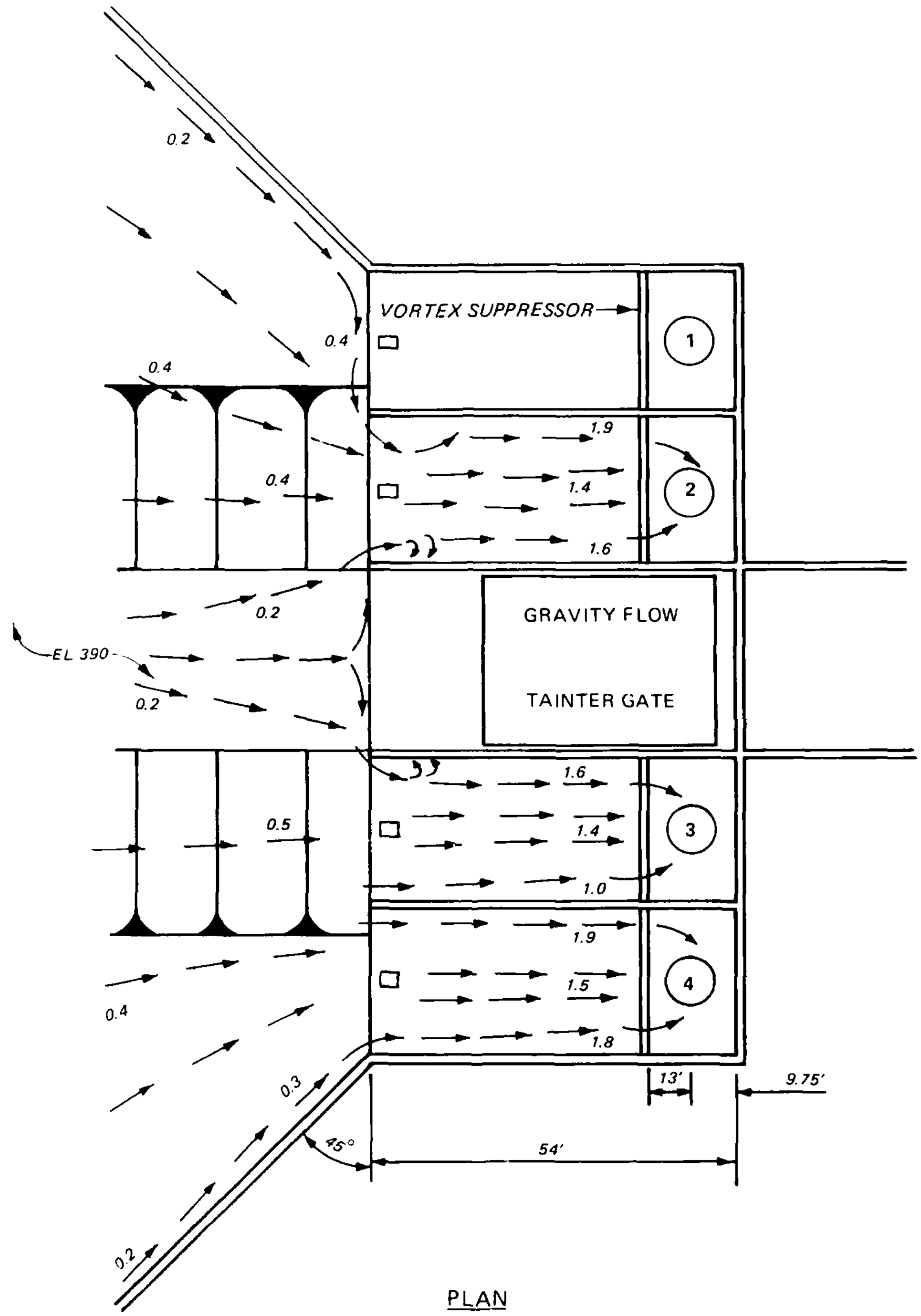
NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND MEASURED 1 FT ABOVE BOTTOM.
Q = 1,025 CFS PER PUMP
WATER-SURFACE EL 421

SCHEME C SUMP
MAGNITUDE & DIRECTION OF CURRENTS DURING PUMPING
PUMP OPERATING: 4



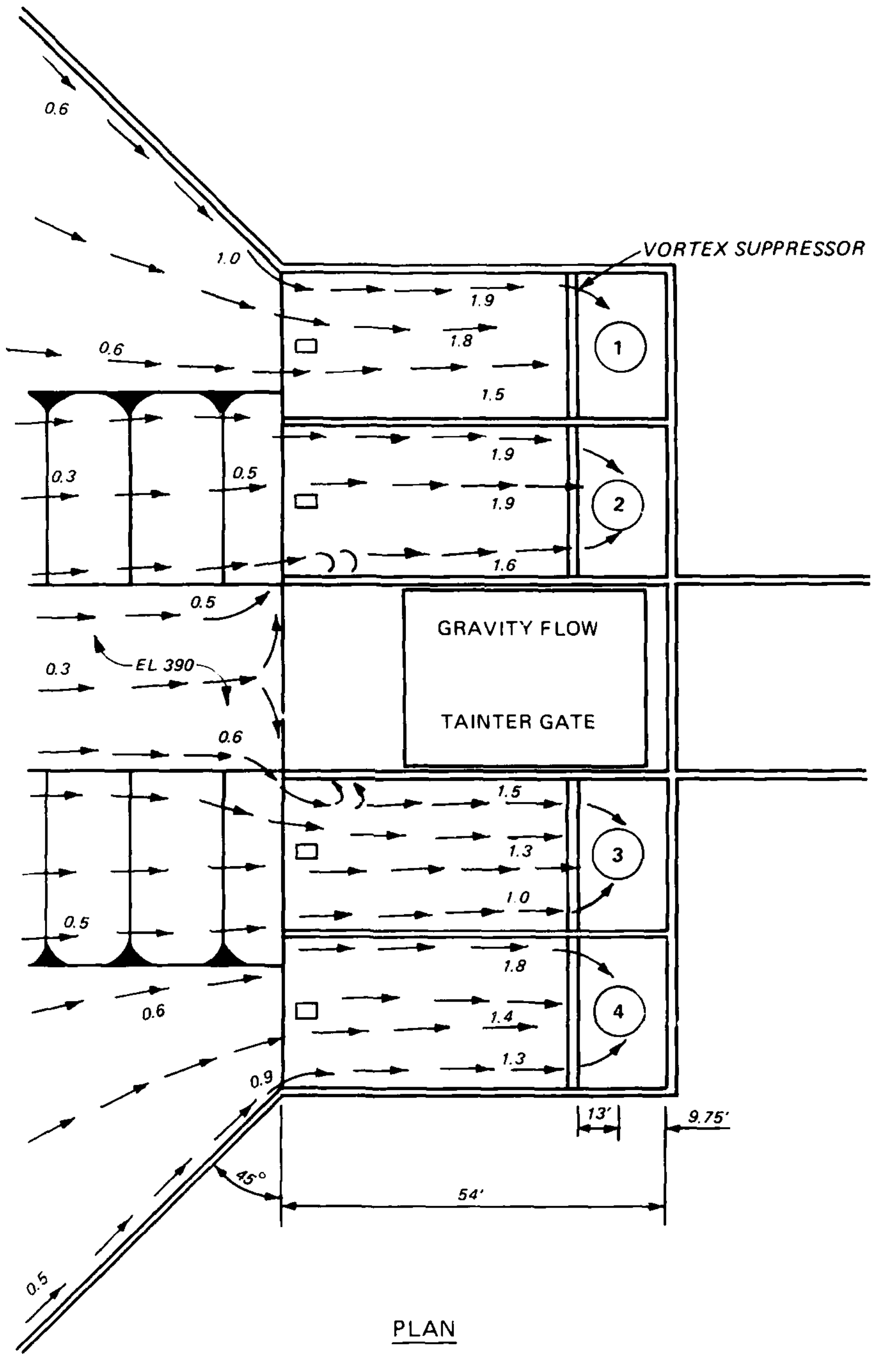
NOTE. VELOCITIES ARE IN PROTOTYPE FEET PER SECOND MEASURED 1 FT ABOVE BOTTOM
Q = 1,025 CFS PER PUMP
WATER-SURFACE EL 421

SCHEME C SUMP
MAGNITUDE & DIRECTION OF CURRENTS DURING PUMPING
PUMPS OPERATING: 3 & 4



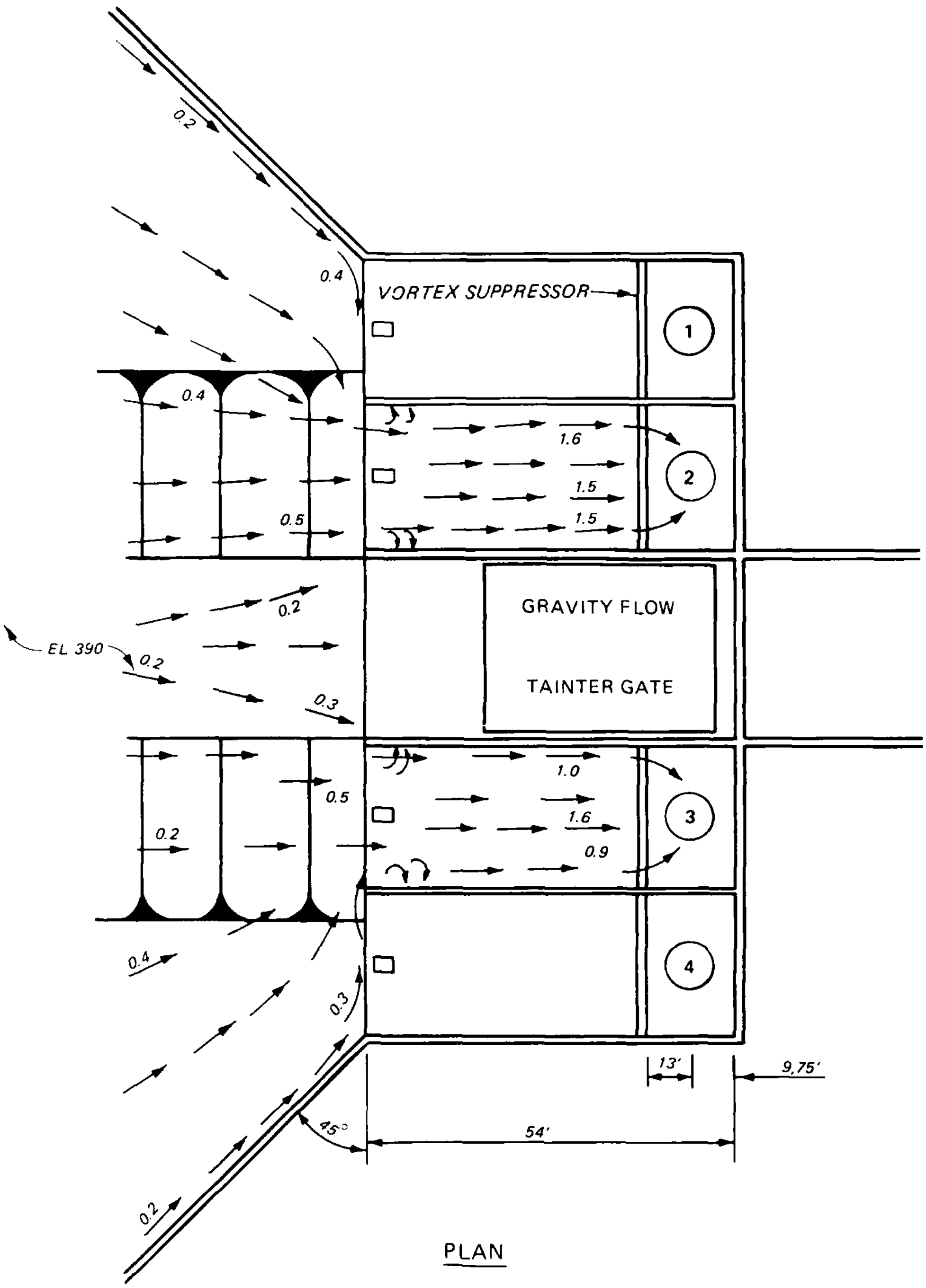
NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND MEASURED 1 FT ABOVE BOTTOM. Q = 1,025 CFS PER PUMP WATER-SURFACE EL 421

SCHEME C SUMP
MAGNITUDE & DIRECTION OF CURRENTS DURING PUMPING PUMPS OPERATING: 2, 3, 4



NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND MEASURED 1 FT ABOVE BOTTOM.
Q = 1,025 CFS PER PUMP
WATER-SURFACE EL 421

SCHEME C SUMP
MAGNITUDE & DIRECTION OF CURRENTS DURING PUMPING
PUMPS OPERATING: 1, 2, 3, 4

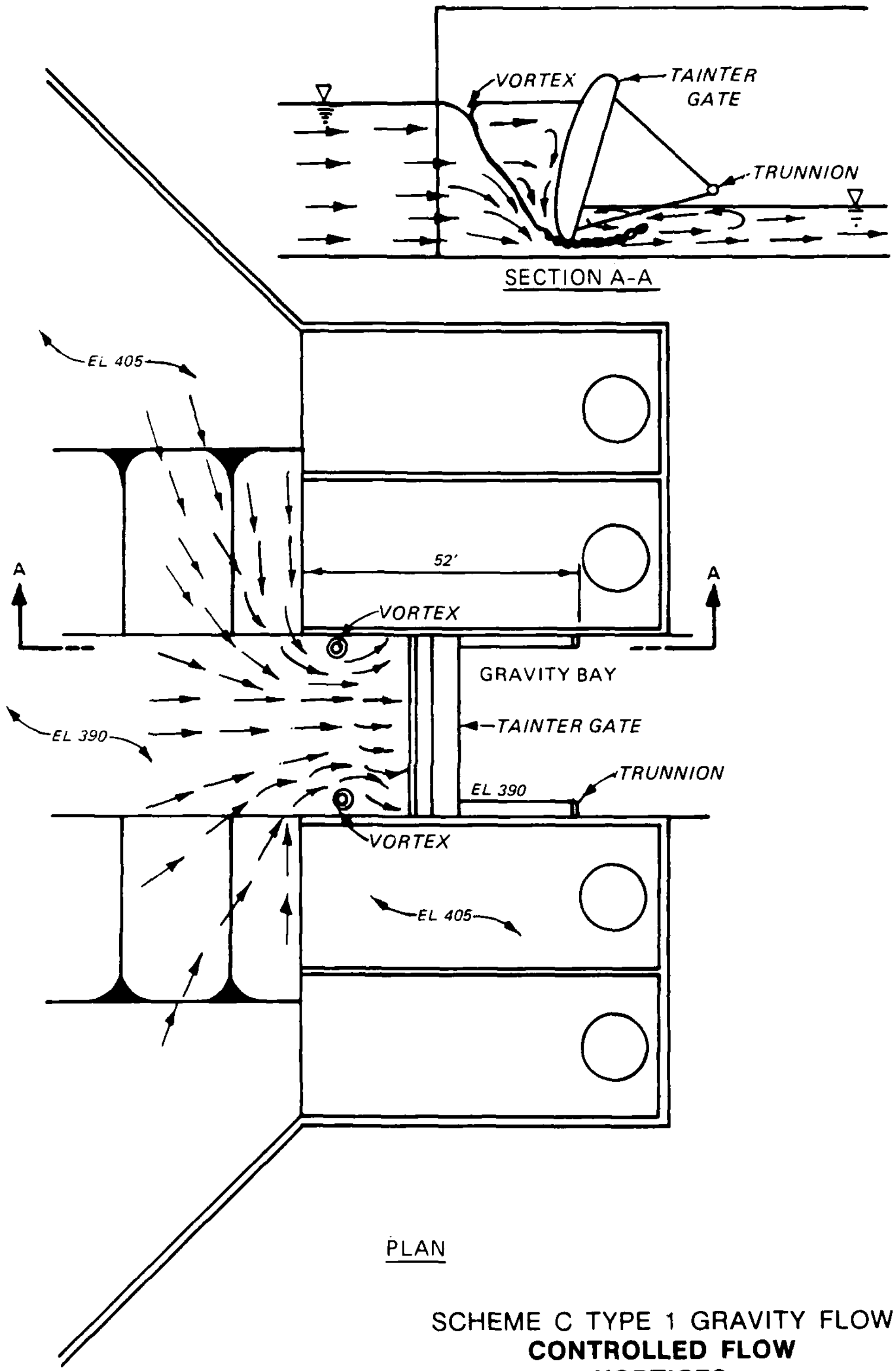


PLAN

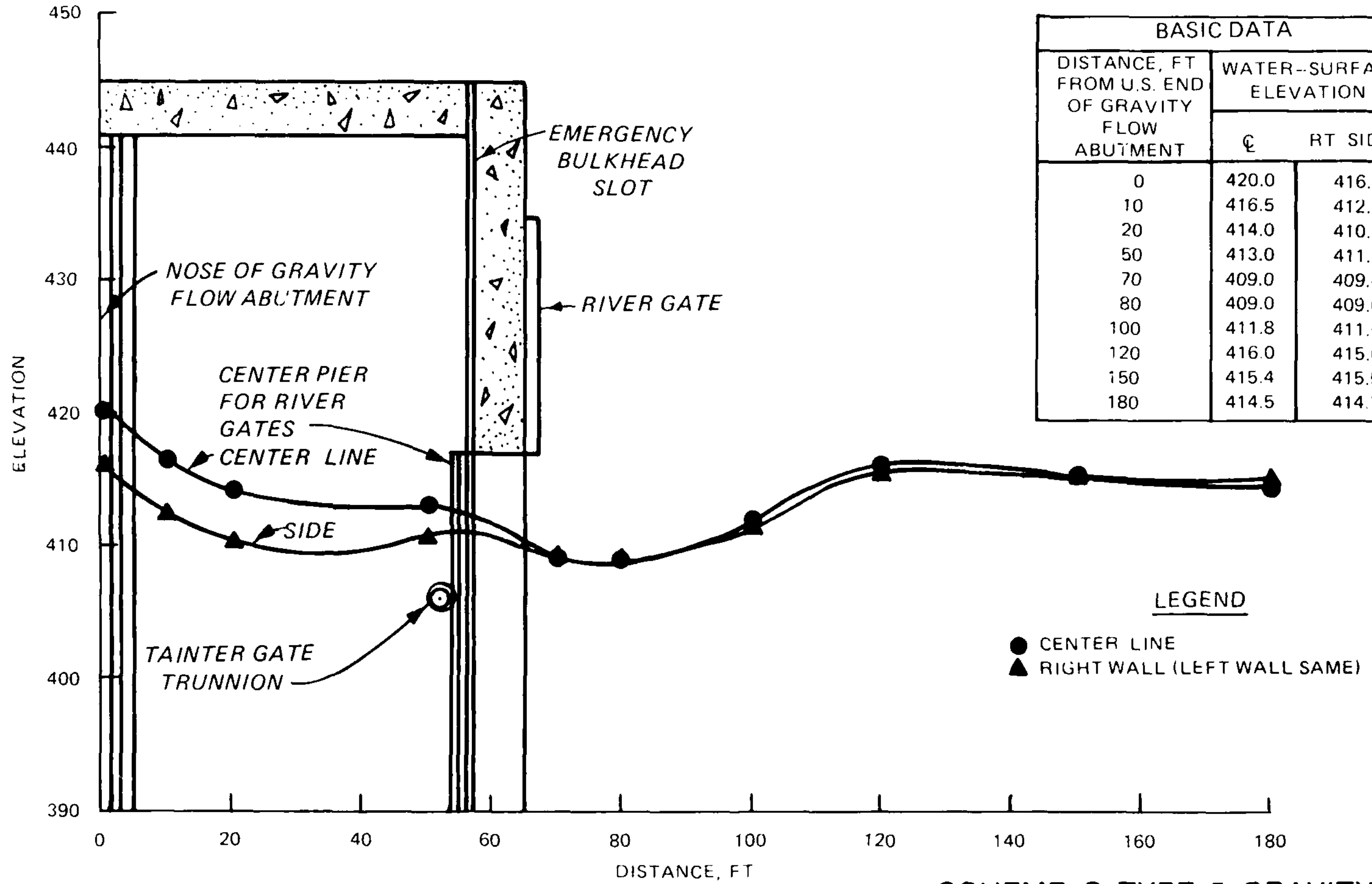
NOTE. VELOCITIES ARE IN PROTOTYPE FEET PER SECOND MEASURED 1 FT ABOVE BOTTOM.

Q 1,025 CFS PER PUMP
WATER-SURFACE └ 421

SCHEME C SUMP
MAGNITUDE & DIRECTION OF CURRENTS DURING PUMPING
PUMPS OPERATING: 2, 3

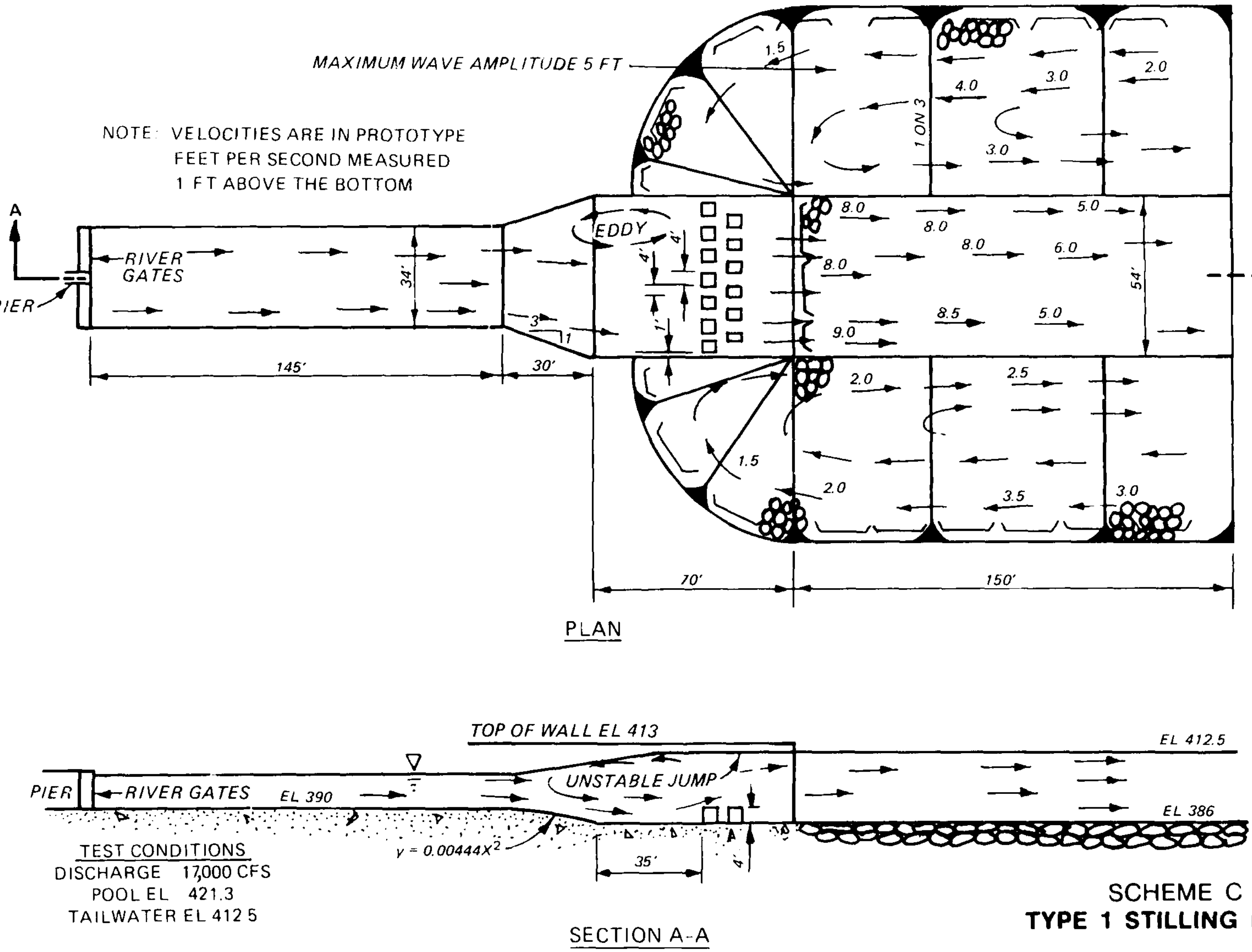


SCHEME C TYPE 1 GRAVITY FLOW
CONTROLLED FLOW
VORTICES
BOTTOM CURRENTS
DISCHARGE 9,800 CFS
POOL EL 426.0

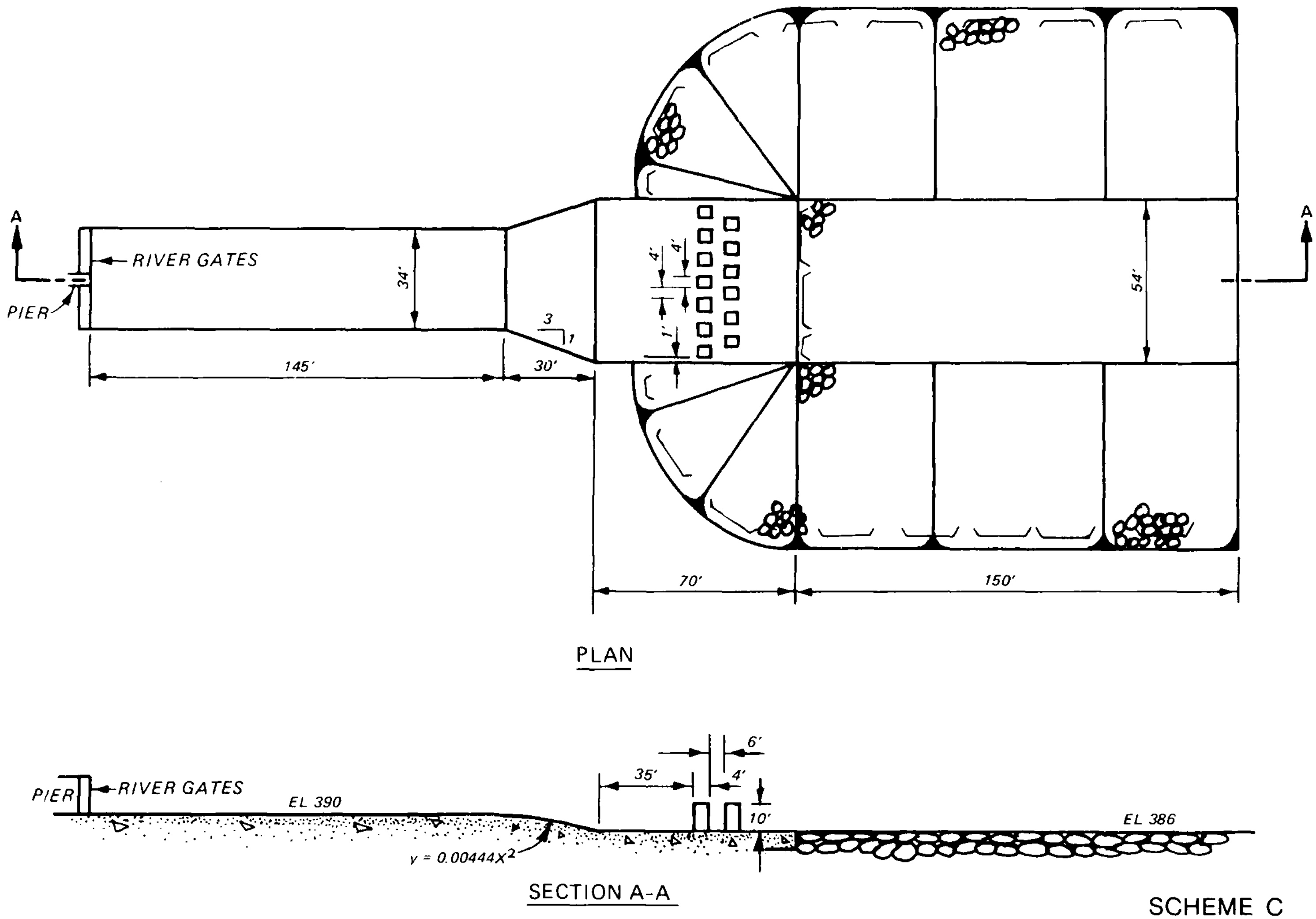


BASIC DATA		
DISTANCE, FT FROM U.S. END OF GRAVITY FLOW ABUTMENT	WATER-SURFACE ELEVATION	
	℄	RT SIDE
0	420.0	416.0
10	416.5	412.6
20	414.0	410.0
50	413.0	411.0
70	409.0	409.0
80	409.0	409.0
100	411.8	411.5
120	416.0	415.6
150	415.4	415.5
180	414.5	414.7

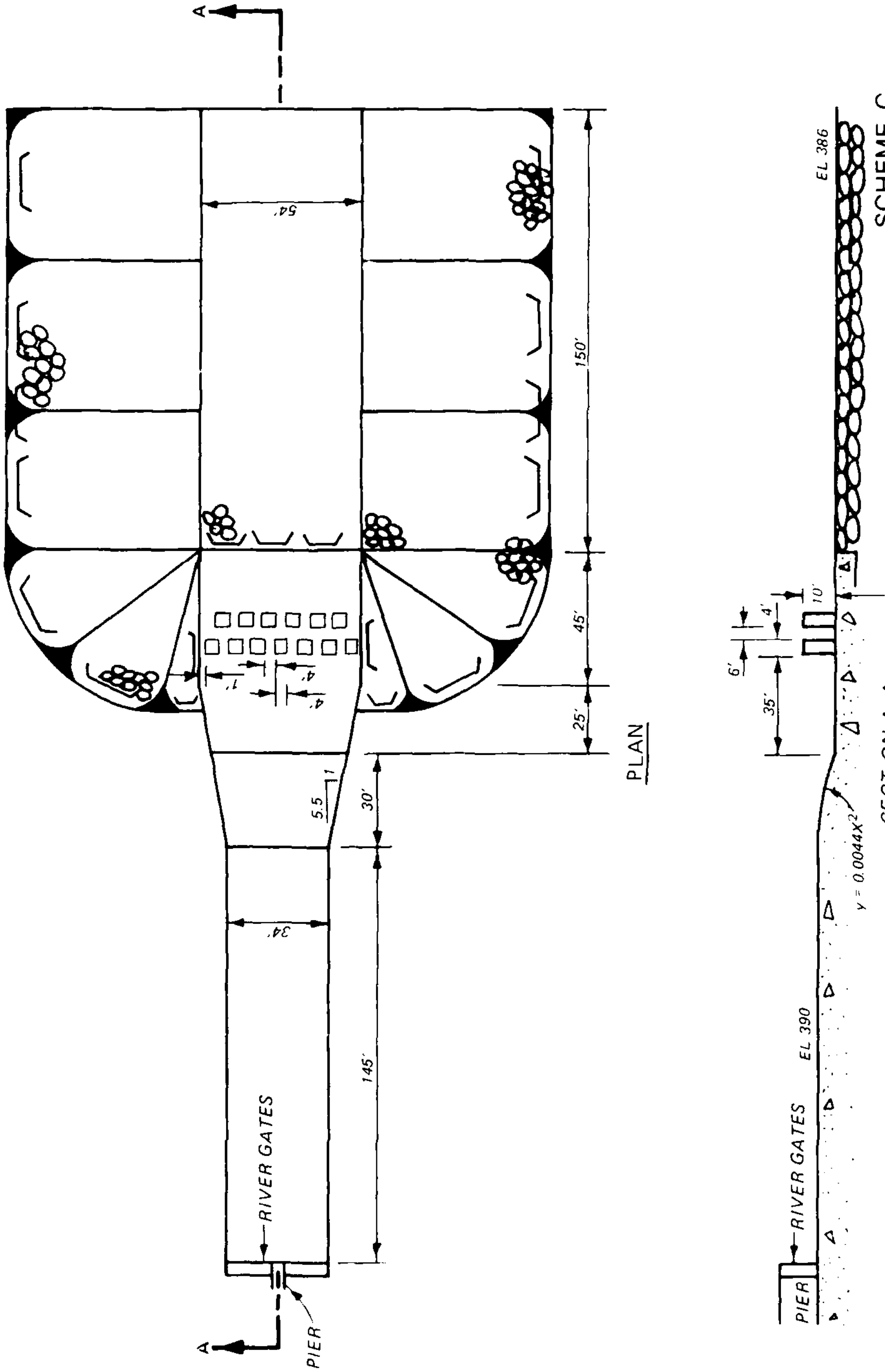
SCHEME C TYPE 5 GRAVITY FLOW
WATER - SURFACE PROFILES
POOL EL 422.0; TAILWATER EL 414.5
DISCHARGE 17,000 CFS



SCHEME C
TYPE 1 STILLING BASIN

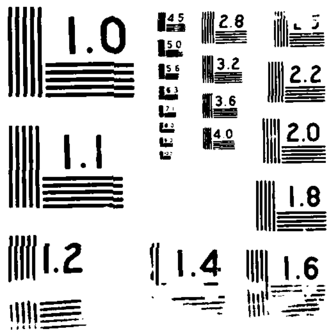


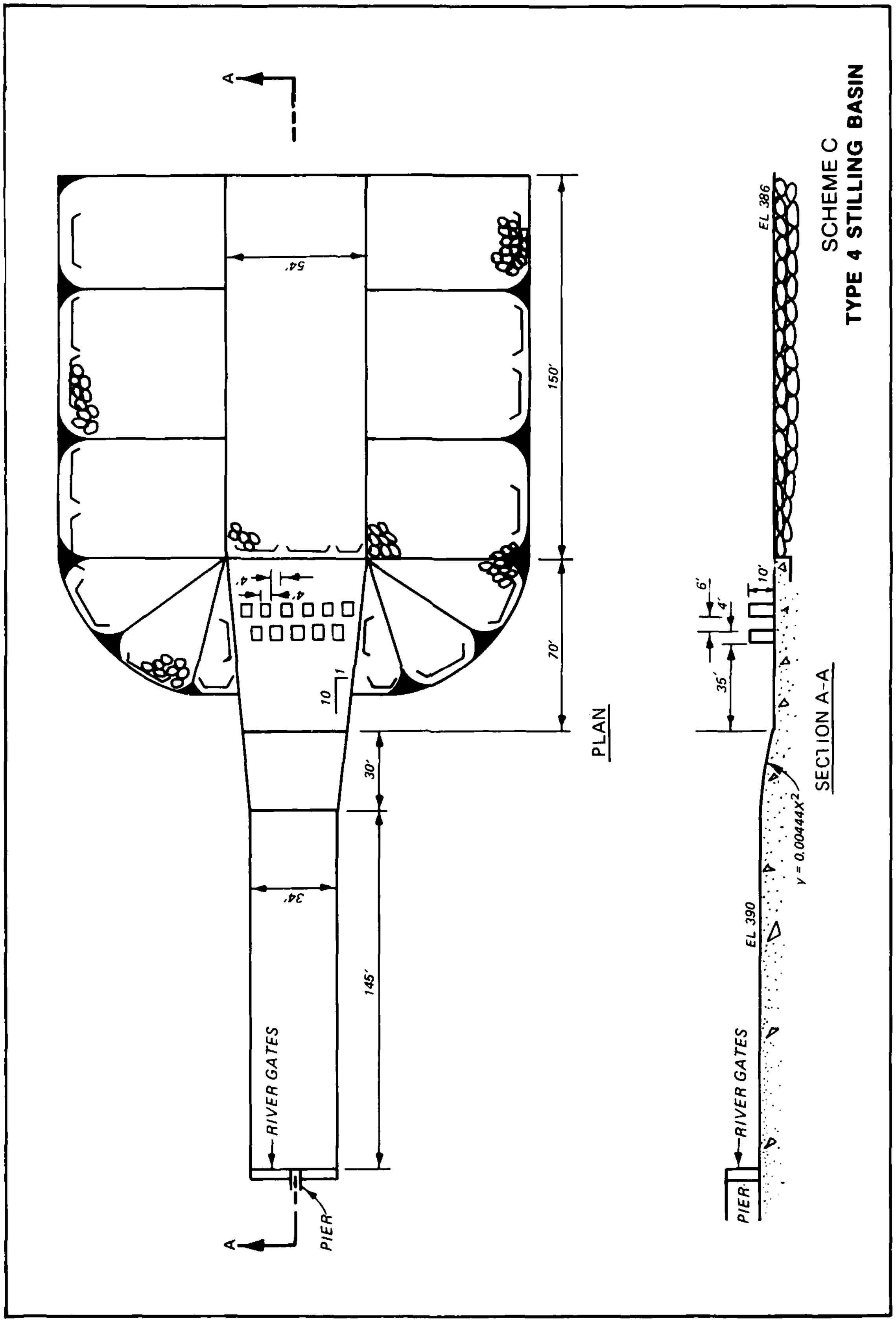
SCHEME C
TYPE 2 STILLING BASIN



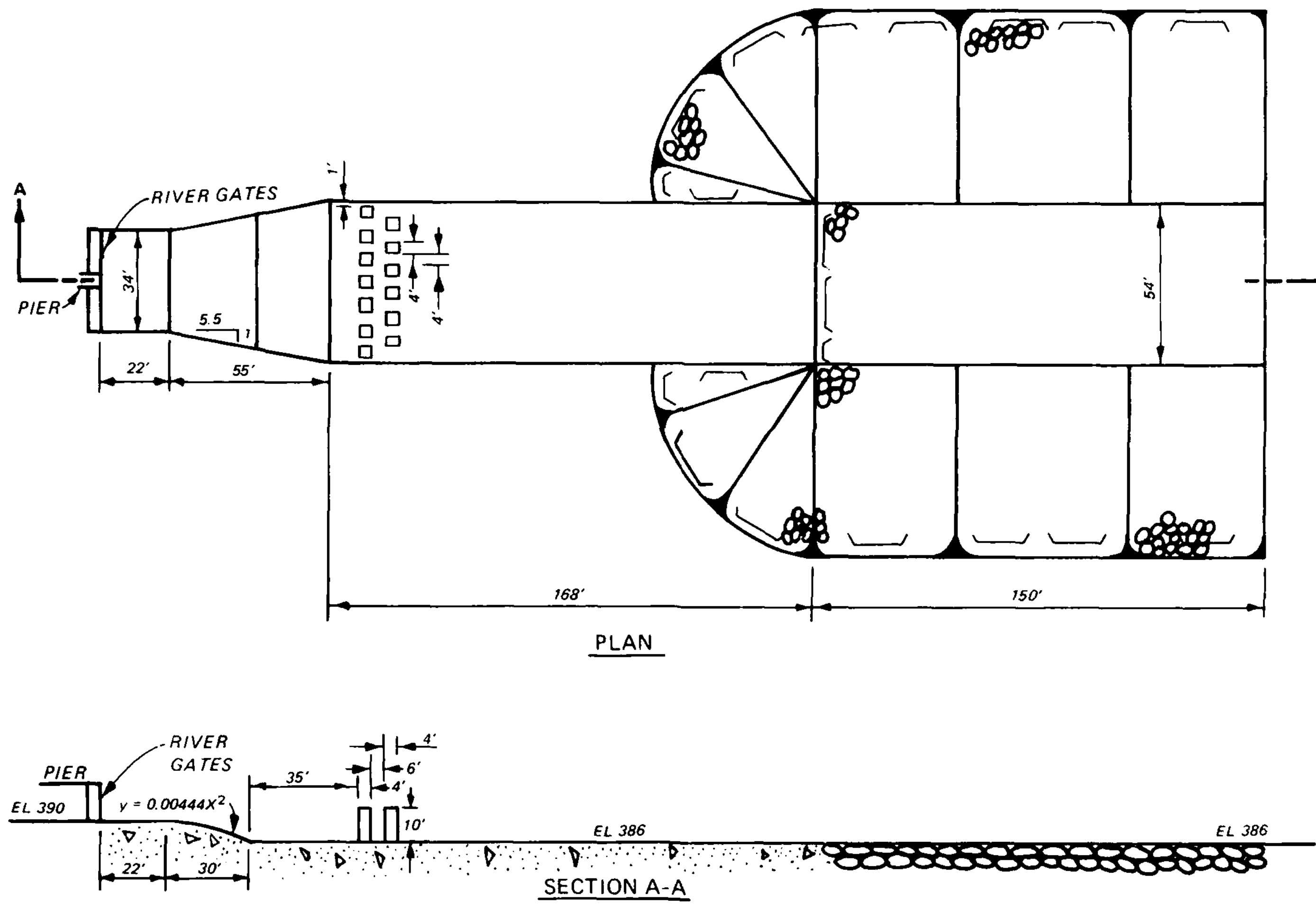
SCHEME C
TYPE 3 STILLING BASIN

AD-A194 387 POND CREEK PUMPING STATION SOUTHWESTERN JEFFERSON 2/2
COUNTY KENTUCKY; HYDRAU (U) ARMY ENGINEER WATERWAYS
EXPERIMENT STATION VICKSBURG MS HYDRA B P FLETCHER
UNCLASSIFIED APR 88 WES/TR/HL-88-7 F/G 13/11 NL


1.0
1.1
1.2
1.4
1.6
1.8
2.0
2.2
2.8
3.2
3.6
4.0

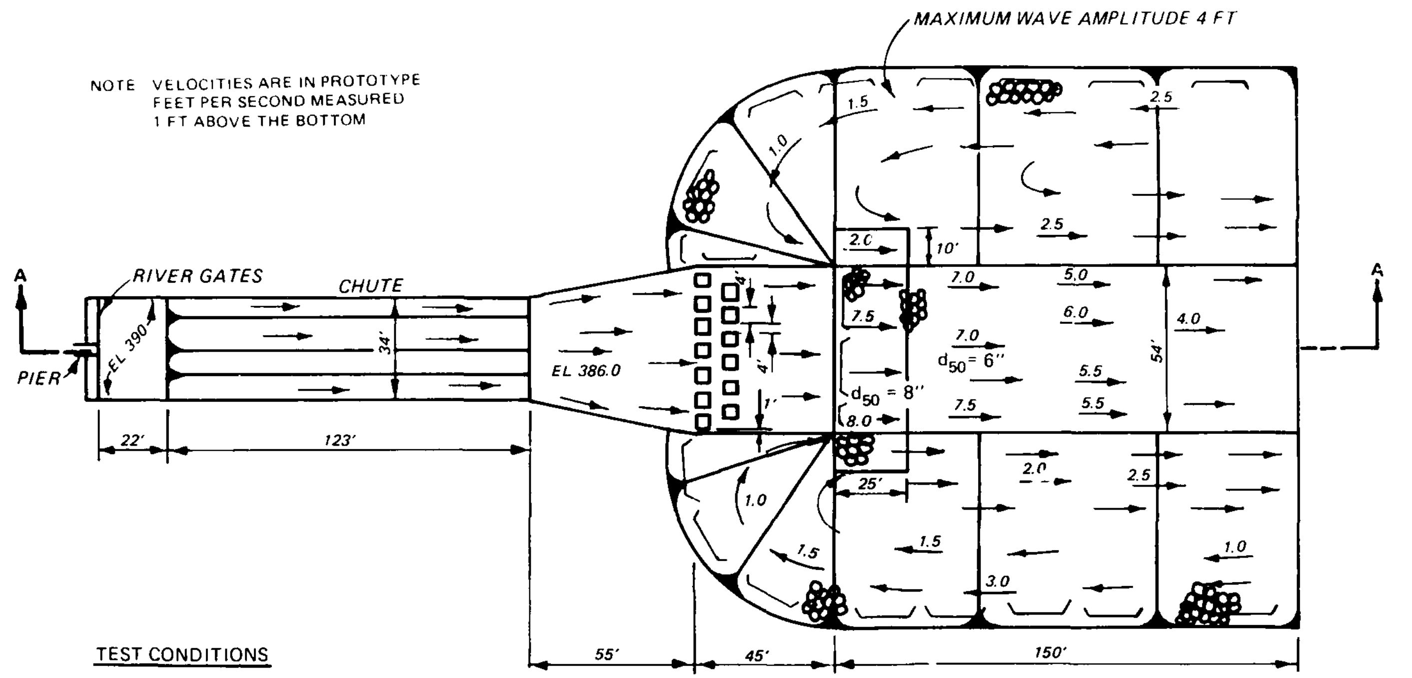


SCHEME C
TYPE 4 STILLING BASIN



SCHEME C
TYPE 5 STILLING BASIN

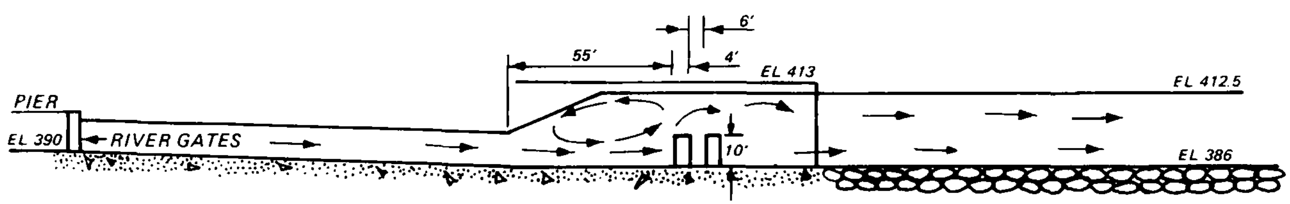
NOTE VELOCITIES ARE IN PROTOTYPE FEET PER SECOND MEASURED 1 FT ABOVE THE BOTTOM



PLAN

TEST CONDITIONS

DISCHARGE 17,000 CFS
POOL EL 421.3
TAILWATER EL 412.5



SECTION A-A

SCHEME C TYPE 2 DESIGN RIPRAP

TYPE 6 STILLING BASIN
UNCONTROLLED FLOW
ADOPTED DESIGN

END
DATED
FILM
8-88
DTIC